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Improving the design and management of agile supply chains: feedback and application in the context of humanitarian aid

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Résumé Court

Le secteur humanitaire a fortement évolué ces dernières années. Il est poussé à plus de transparence et doit rendre des comptes aux donateurs. Dans ce contexte, notre étude vise à expliciter, mesurer et améliorer l'une des principales caractéristiques des chaines logistiques humanitaires : leur capacité à répondre rapidement et adéquatement aux changements à court terme. Cette capacité, l'agilité, est fortement influencée par la manière dont le réseau logistique est conçu et dimensionné. Notre seconde problématique consiste donc à assurer un niveau déterminé d'agilité aux chaînes logistiques humanitaires en les aidant à mieux positionner leurs ressources. L'objectif est de montrer que l'on peut obtenir ce niveau de service en maximisant l'efficience du réseau. Nous avons donc quantifié, en terme de coûts, l'impact de plusieurs décisions stratégiques comme le niveau de service, la proximité des fournisseurs et le degré de centralisation du réseau.

Short Abstract

A push for increased professionalism during disaster relief operations has been reinforced over the last decade. The uncertainties humanitarian organisations have to cope with and the vital importance of their success has incited them to develop their ability to respond quickly and adequately to short-term changes. This agility capability is becoming highly prized by the private sector. Starting from a framework of supply chain agility, this thesis analyses humanitarian methods and defines an agility maturity model aiming to measure and improve the agility capability of a supply chain. As agility often depends on the adequate balance between delivery capacity and needs, our second problem statement aims to design a logistics network that can operate under high levels of uncertainty so that for a given level of service in terms of agility, efficiency is maximized. Our study quantifies the impact on costs of various decisions, such as network design, supply strategy or level of service.

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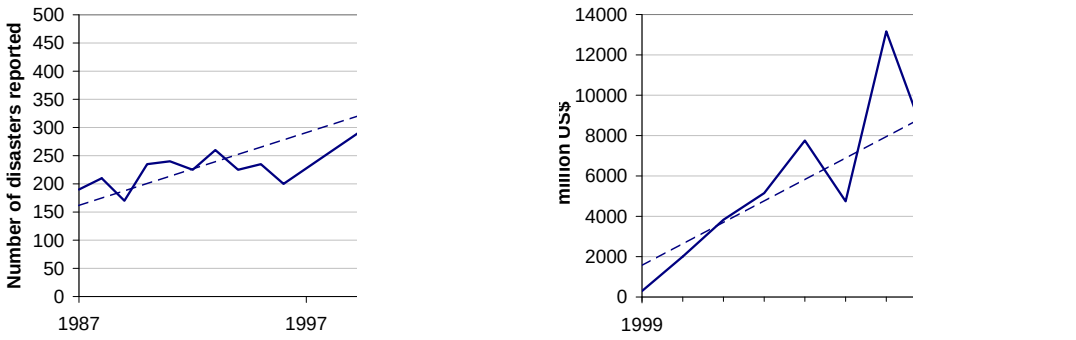
Introduction

Motivations and background

The humanitarian sector has been confronted with many changes over the last ten years. On the one hand, the crisis profile is evolving toward more small- and medium-sized disasters, so there are more operations all over the world. On the other hand, donors are pledging millions in donations in an economic context that imposes rationalisation (see figure 1). Therefore, they are asking for more accountability and transparency and have less tolerance for the fire-fighting mentality that characterised most humanitarian operations in the past. As a consequence, disaster relief needs more structure; it has to become more results-oriented to avoid direct friction with the private sector. The first step of our work consists in the formal characterisation of humanitarian supply chains in order to comprehend their specificities and needs.



(a) Evolution of the number of natural disasters [Hoy+07] (b) Evolution of funding in million US$ [UNO10]

Figure 1: Natural disasters, facts and trends

Humanitarian organisations often have to quickly implement complex supply chains under high levels of uncertainty regarding demand and supply as well as the environment, thus becoming specialists at being agile. Starting from a framework of supply chain agility, the second part of this thesis analyses humanitarian methods and defines an agility maturity model aimed at measuring, improving and transferring the agility capabilities of humanitarian or commercial supply chains.

Working on the clarification of what exactly enables humanitarians to be reactive and effective would benefit both the private sector and humanitarians. Indeed, many authors agree on the importance of agility. Kidd goes even as far as asserting that agility is “the future business system that will replace the mass production businesses of today” [Kid95]. Having a logical,

objective, robust and reproducible method for assessing supply chain agility is therefore becoming of prime importance for both commercial and humanitarian sectors. First of all, it would enable and encourage internal reflection. Secondly, it would provide organisations with a common discussion tool that can be used to offer proof of their competitive advantage. This is obviously true for the private sector, but it is also valid for humanitarians, who could use this approach as evidence of their good agility level.

Such a tool would also provide supply chain managers with effective ways of collaborating with other stakeholders, thus facilitating benchmarking and cross-learning. Eventually, it would lead to better measurement of performance levels, improved management skills and abilities, and increased facilitation of knowledge management, which is not only a path toward self-improvement, but also a requirement for meeting donors' expectations.

As agility often depends on the adequate balance between delivery capacity and needs, our second problem statement aims to design a humanitarian logistics network so that for a given level of service in terms of agility, efficiency is maximised. The third part of this thesis therefore quantifies the impact on costs of various decisions, such as network centrality, supply strategy or level of service.

For this purpose, we have developed a mixed integer linear programme to give the best locations for positioning humanitarian resources, namely relief items and material means of transportation such as vehicles. The objective function of the programme is to minimise the costs of the response. The effectiveness and responsiveness of the response are considered as constraints. In other words, the programme determines which supply chain design would enable an organization to meet its targeted level of service at a lesser cost. The practical result for organizations is a quantified analysis for knowing how many warehouses should be opened, why and where. We also conducted a sensitivity analysis of various parameters in order to clarify which decisions impact the costs of the response. We therefore varied the inputs and constraints of the model to analyse the difference between a centralised or a decentralised network, between global or local supply strategies, and to quantify the effects of a high level of service in terms of costs.

These runs were made at a regional level; that is to say, we divided the world into 21 regions, each one being approximately the same size as Australia. Once we knew which regions should host a warehouse, we jumped to a local level and used a principal component analysis to define relevant indicators, such as accessibility, telecommunications, corruption and the level of security. These indicators were then weighted following a design of experiment and used to find the best location, this time at a country-wide level. This local analysis was driven by field specificities, as no humanitarian organisation would willingly build a warehouse in an unsafe or inaccessible area.

Working on the configuration and dimensioning of a logistics network under demand, supply and environmental uncertainties would benefit both humanitarians and the private sector. The increased volatility of demand, supply and the environment are becoming a common concern for most business lines, from the fashion industry to humanitarian aid. This thesis proposes a method for designing a supply chain under such uncertain conditions. For humanitarians it would provide an optimisation of their stock location and as a result, a fast and adequate response at a lesser cost. This is an area of research that many humanitarian organisations, such as the International Federation of the Red Cross and Red Crescent Societies (IFRC), World Vision International or the French Red Cross recognise as one of their major issues. We have therefore designed our study on the basis of input and discussions with humanitarian practitioners. Our model fits the specifications given by the IFRC and provides a

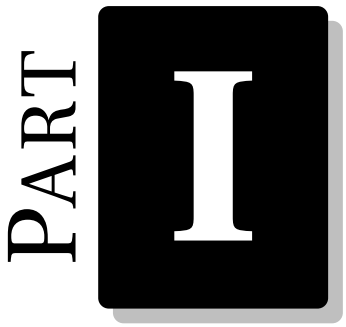
specific, quantified analysis of the impact of their choices with regard to the level of service or local capacity building on their level of efficiency. We therefore give some recommendations, aiming to help the IFRC define its logistics strategy.

This research has allowed us to analyse the trend toward decentralisation taken recently by humanitarians, helping them go one step further by better positioning their resources and measuring the impacts of this new supply chain design on their agility and efficiency.

These reflections on the decentralisation of a supply chain, its motivations and the importance of each decision's variables are of prime importance in our globalised world, for any line of business. All in all, this thesis analyses and develops areas where humanitarian workers and their corporate counterparts could mutually benefit from each others' expertise.

Research Objectives

1. Characterise humanitarian supply chains in order to make their specificities and needs explicit.
2. Provide a clear framework of supply chain agility and a model to assess it in an objective, robust and reproducible way.
3. Characterise the supply network problem of humanitarian organisations or any private company working under high levels of uncertainty regarding demand, supply and environment. We propose an optimisation model to quantitatively analyse the impact of various strategic choices on operations efficiency.



Humanitarian Supply Chains

Context, Particularities and Research Statements

Purpose: No relief operation is similar to another. The nature, the number and the incentives of stakeholders vary tremendously from one operation to another. Add to that the long travel distances and the magnitude of the needs and you have a glimpse of all the factors which exacerbate the complexity of humanitarian operations and drain the logistical capacity of the agencies on the ground. The aim of this first part is to analyse the main features of humanitarian supply chains, and to evaluate their strengths, weaknesses, opportunities and threats.

Design/methodology/approach: The methods used for this research are case study research and literature review.

Findings: We provide an overview of what a humanitarian supply chain is. We analyse its particularities and their consequences on the management of the supply chain. The literature is reviewed in order to define and position our research questions.

Research implications: This part constitutes a first step to better define the needs of humanitarian supply chains and thus define the research objectives that will be developed in the second and third parts of this thesis.

1

Disaster Management: facts and recent changes

Disasters are crises, either natural or man-made, that local governments cannot face with their own resources. They may result from a wide range of crises, from earthquakes to droughts, conflicts or industrial accidents. Some may cause hundreds of thousands of deaths; others may have an impact on only a limited number of people. Some may affect a population for only a couple of weeks, such as in the case of heat waves, whereas others may last for years. The crisis in Darfur is an example of those which seem to last forever. Table 1.1 summarizes the main types of disasters.

Each of these disaster types requires a specific response. The relief operations deployed after a disaster vary according to the location of the crisis, its intensity, its nature, the stakeholders involved and many other elements. All these factors have an impact on the design and implementation of humanitarian supply chains. Yet we agree with Chandes and Paché that "it would be tempting, but dangerous and inefficient, to think that each natural or man-made disaster is unique, and therefore calls for a customized response from which no general lesson will be learned for future events. [...] Beyond the objective differences between these situations, it is essential to determine their similarities so as to accelerate the mobilization of resources and actors."[CP10]

Still, it is very difficult to study each and every disaster. The generalisation induced would make our findings too general to be of any use. We have therefore limited the scope of our study to natural disasters only. By excluding man-made disasters, we have reduced the complexity of the study. It decreases the proportion of disasters that take place in a politically volatile climate

Table 1.1: Explaining Disasters - From [Was06b]

	Natural	Man-Made
Sudden-onset	Earthquakes, Hurricanes, Tornadoes, etc.	Terrorist attacks, Coups d'état, Chemical leaks, etc.
Slow-onset	Famine, Drought, Poverty, etc.	Political crises, Refugee crises

Table 1.2: Disaster Classification - From [Sch+08]

Disaster Subgroup	Definition	Main Disaster Type
Geophysical	Events originating from solid earth	Earthquakes, Volcanoes, Mass movement (dry)
Meteorological	Events caused by short-lived/small-to-meso scale atmospheric processes (in the spectrum from minutes to days)	Storms
Hydrological	Events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up	Flood, Mass movement (wet)
Climatological	Events caused by long-lived/meso-to-macro scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability)	Extreme temperature, Drought, Wildfire
Biological	Disasters caused by the exposure of living organisms to germs and toxic substances	Epidemics, Insect infestations, Animal stampedes

and therefore have an exceedingly uncertain environment. Table 1.2 provides a classification of natural disasters. This section clarifies and categorises the diversity of scenarios that may occur. To that end, we compare five disasters of similar nature and intensity, but which nevertheless present huge differences. One relief operation, the response to the 2006 Yogyakarta earthquake, will then be further detailed in order to illustrate what a humanitarian operation is and how a humanitarian supply chain is designed and run.

With around 450 to 500 natural disasters a year, there are many examples available for analysing and comparing relief operations. To illustrate our study, we will therefore refer to past disasters. In the interest of being consistent as well as to helping readers' understanding, we will refer to the same disasters and add layers to our comparisons throughout this thesis.

In the context of international relief efforts, many factors influence the sequence of events. In order to compare only what is comparable and to analyse the influence of these factors, we have selected disasters of a similar nature and intensity. A comparison of the deadliest earthquake per year since 2004 will therefore appear as a guiding thread throughout this thesis (see table 1.3 on the facing page).

1.1 Guiding thread 1 - How and why disaster management differs from one crisis to another

As you can see in table 1.3, the category "deadliest earthquake per year" may still be too broad. The death toll depends on many factors, from the magnitude of the earthquake to its geographical location, the weather conditions, and the population density and vulnerability around the epicenter.

To provide a better comparison of each operation, we have therefore summarised the context in which the earthquakes took place, adding basic elements such as the season and the distance

Table 1.3: Guiding thread 1 - Deadliest earthquakes by year, short comparison
Sources :
Magnitudes, depths, fatalities, distances, time/season :[USG]
Number of Affected, Damage: [EM-]
International Aid : [UNO05b]

	2010 Haiti (after 3months)	2008 Sichuan	2006 Java (Indonesia)	2005 Pakistan	2004 Indian Ocean
Magnitude (Mw)	7.0	7.9	6.3	7.6	9.1
Depth (km)	13 km	19 km	10 km	26 km	30 km
N° Killed	222,570	87,587	5,749	80,361	227,898
N° Affected	2,090,877 displaced	45,976,596	3,177,923	5,284,622	2,431,613
Distance to nearest big city	25 km from Port-au-Prince	80km from Chengdu	20 km from Yogyakarta	105km from Islamabad	250 km from Banda Aceh
Time/Season	Tuesday, 04:53 PM January	Monday, 02:28 PM May	Saturday, 05:53 AM May	Saturday, 08:50 AM October	Sunday, 07:58 AM December
Damage (million US$)	>8000	492	3100	6200	9391
International Aid (million US$)	Appeal 1500, 50% pledged	310	133	1171	7000

to the nearest big city in table 1.3. The following paragraphs illustrate the major elements that have had an impact on the relief operations deployed to respond to these earthquakes.

1.1.1 Haiti 2010 - Population density and vulnerability

The impact of a disaster depends not only on the nature and the intensity of the disaster, but also on its location. The same earthquake around San Francisco, where buildings are built with specific materials and local resources are prepared to respond, will not have the same impact as one that strikes a poor, unprepared country such as Haiti or a region such as the high mountains of Pakistan during winter. It also depends on the population density. The earthquake in Haiti, for example, occurred less than 25 kilometres from the capital, thus causing major damage to vital infrastructure, such as hospitals, seaports and airports, roads and communications systems. Means of action were also cruelly lacking. The number of machines capable of digging on the island was so desperately low that people had to search through the rubble bare-handed, thus limiting the number of people rescued. Infrastructure and means of action were therefore either damaged or missing. Local capacity and leadership were also adversely affected. Among the dead were aid workers. At least 85 United Nations personnel working with MINUSTAH[1] were killed, among them the Mission Chief and his deputy [BBC10]. As for the local government, although it survived the destruction of the presidential palace and the national assembly building, its leadership and coordination capacities were overwhelmed by the magnitude of the disaster. A local journalist at the time remarked that the Haitian president “has waited for nine days before officially speaking to the country. Like Godot, we were waiting for him and we are still waiting” [Val10]. This lack of local capacity caused many

[1] United Nations Stabilization Mission in Haiti

difficulties during the first days of the humanitarian response. In this regard, the response to the 2008 Sichuan earthquake was entirely different.

1.1.2 Sichuan 2008 - Local capacity and cause-effect chain

Many actors join forces both before and during relief operations. INGOs[2], UN Agencies, local NGOs[3], local governments, the military, external governments and many others are involved in disaster management. The presence of a local authority able and willing to act as a central coordinator is a primary element for shaping relief operations. The presence of an army, local or not, also affects the collaborative networks, as does the presence of such local capacity as a UN Resident Coordinator or trained volunteers. To provide assistance after the 2008 earthquake, humanitarian organisations had to get the government's approval. Relief efforts were coordinated by local authorities, and the army participated actively and extensively in operations. "China has mobilized more than 130,000 army and paramilitary troops to the disaster area" (IFRC Operations update n° 5 22 May 2008). The strength and leadership of the local government therefore had a deep impact on relief operations in China.

Another element affected the operations in the Sichuan province: heavy rain increased the possibility of floods and landslides in earthquake-damaged areas. It threatened 700,000 people with the possible rupture of lakes caused by earthquake landslides (Reliefweb, operations update 27 May 2008). Combined with rocks and mudslides on the roads, the bad weather also held up rescue, medical and other disaster relief teams, especially in remote and rural areas. Disease control also proved challenging with a lack of staff and equipment for environmental disinfection. (IFRC Operations update n° 5 22 May 2008)

1.1.3 Pakistan 2005 - Environmental complexity: no roads, no trucks...

Thus, the complexity of the environment hindered relief operations in Sichuan. This is often the case during humanitarian relief efforts. A disaster that affects many small villages in high mountains at the beginning of the winter season, like the 2005 Pakistan earthquake, is a real challenge to respond to. No truck can navigate the long-distance footpaths of those high mountains. In this specific case, finding adequate and available transportation for reaching victims was not an easy task. The end-to-end supply chain is much, much longer and more expensive to activate in such a difficult context.

In the case of the 2005 Pakistan earthquake, roads were blocked by landslides and bad weather, and survivors had "as little as three weeks to get shelter before the Himalayan winter sets in with heavy snows and freezing temperatures, closing roads and stranding remote villages" (Qayum, 2005). The only means of transportation at the disposal of humanitarian workers for delivering relief items to victims were... donkeys. To increase their delivery capacity, humanitarian workers brought donkeys from lower regions to complement their "vehicle fleet", but with limited results as the donkeys were subject to vertigo.

1.1.4 Indian Ocean Tsunami 2004 - Human resources: many stakeholders, many incentives, many difficulties

Many stakeholders with various incentives can be involved in operations. And the bigger the disaster, the higher the number of NGOs that will have sufficient funding to participate in the

[2] International Non-Governmental Organization
[3] Non-Governmental Organization

humanitarian response... and the more difficult coordination will be. The 2004 Indian Ocean Tsunami is one example of the chaos that can happen when self-regulation does not take place. Many factors, from the magnitude of the disaster to the presence of many Western tourists "generated massive media attention which in turn prompted an inordinate public response to donate money as people felt a moral obligation to help. There was also an unprecedented wave of governments' attention which was not necessarily free of a political agenda[...] Due to the lack of adequate regulation and the presence of too many players chaos ensued in Sumatra after the tsunami" [Was06b]. Here again, the presence of a local authority able and willing to act as central coordinator is one of the main elements which shapes relief operations.

1.2 Yogyakarta earthquake 2006

The previous paragraphs briefly describe the main specificities of the biggest earthquakes in recent years, and their impacts on relief operations. We will now provide a deeper analysis of one of them: the 2006 Yogyakarta earthquake. This specific disaster was chosen as it was the first operation conducted by the International Federation of the Red Cross and Red Crescent Societies (IFRC) with its newly decentralised supply chain. It was also sufficiently "small" to allow a case study analysis and it happened less than a year before the beginning of our research work, which gave a perfect time-frame for conducting interviews.The situation was stable enough to allow humanitarian workers to spare some time for interviews, but not too old, so it remained clear and fresh in their memories.

1.2.1 Methodology: Case Study Research

To better understand humanitarian supply chains, we designed and conducted case study research. Indeed, "the case study method allows investigators to retain the holistic and meaningful characteristics of real life events – such as individual life cycles, organisational and managerial processes, neighbourhood change, international relations and the maturation of industries" [Yin02]. Data was collected through documents, archival records and interviews of practitioners working in various regions (Europe, the Middle-East or Africa) and at different organisational levels (headquarters, regional logistics centers or in the field).

1.2.2 Designing the case study

On November 1st, 2006, the International Federation of the Red Cross (IFRC) received the prestigious European Supply Chain Excellence Award, joining the ranks of past years' winners such as Coca-Cola, Johnson & Johnson, Glaxo SmithKline and Marks & Spencer. In acknowledgement of their success in decentralising their entire supply chain, the IFRC was recognised both as overall winner and best-in-class for the public & non-profit sector category. As they announced the results of their deliberation, the panel judges delivered high praise for the IFRC's performance:

"For scale, responsiveness and performance, (the IFRC) are outstanding: all the more so when you realize that they exist to operate in precisely the places where normal supply chains have broken down; that they have only moral rather than legal charges over their sources of supply and funding; and that despite being a global brand with relatively little direct control over its local operations, it has successfully transformed its supply chain to meet even better the demands that the world places on it."

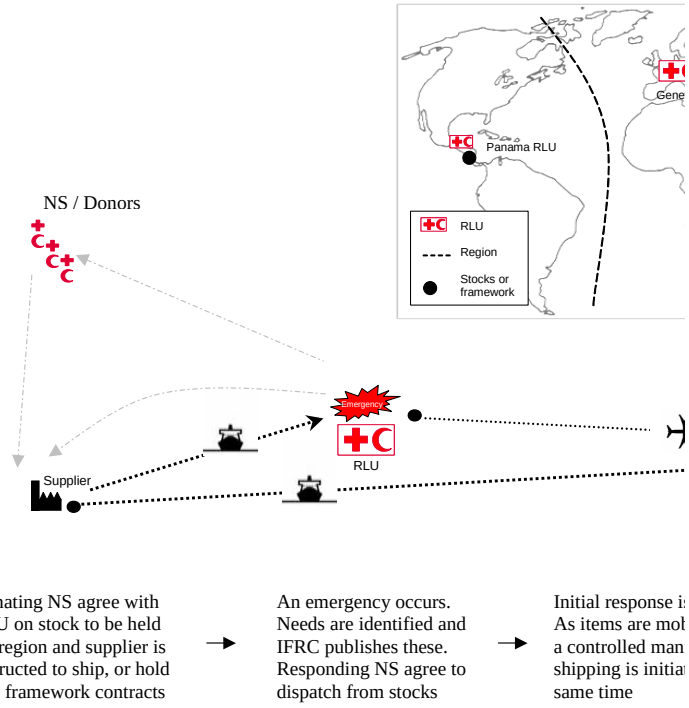


Figure 1.1: IFRC new supply chain, from [Cuc07]
RLU = Regional Logistic Unit.
NS = National Society. The local national society is acting on the disaster site, but other national societies may give a hand and act as donor (relief items, funds or human resources)

Because they had already understood the importance of logistics in relief operations, because they had already reflected on their organisation and developed a clear logistics strategy, and because they agreed to share their knowledge, thoughts and questions, we targeted them for this case study research. At that time, the most recent major relief operation was the response to the 2006 Yogyakarta earthquake, the deadliest earthquake in 2006, which we therefore chose to illustrate how a humanitarian supply chain is set up. The following sections detail our findings. The case study is further detailed in [CGW10] and analysed in [GWC10].

1.2.3 Yogyakarta : first operation with IFRC's decentralized supply chain

In November 2005, the IFRC[4]'s logistics department, under the direction of Bernard Chomilier and then his successor Birgitte Stalder-Olsen, had decided to decentralize the agency's operational capacity by creating three Regional Logistics Units (RLU) in Kuala Lumpur (KL), Panama and Dubai. In the event of a disaster, National Societies (NSs)[5] would be able to call on their area's RLU for help (see figure 1.1). The RLU[6] would then provide assistance in managing the supply chain of relief items through rationalized mobilization and procurement of resources, inventory management, warehousing and fleet support.

In the early hours of May 27th, 2006, the newly established RLU in Kuala Lumpur received its first call to arms as an earthquake hit the Indonesian island of Java with a magnitude of 6.3 on the Richter scale. The province of Yogyakarta bore the brunt of the disaster, suffering

[4]International Federation of the Red Cross and Red Crescent Societies
[5]National Societies. For information, NSsare local NGOs, like the French Red Cross. Present in 186 countries, NSs comprise most of the more than 97 million Red Cross workers, the world's biggest volunteer force.
[6]Regional Logistics Units

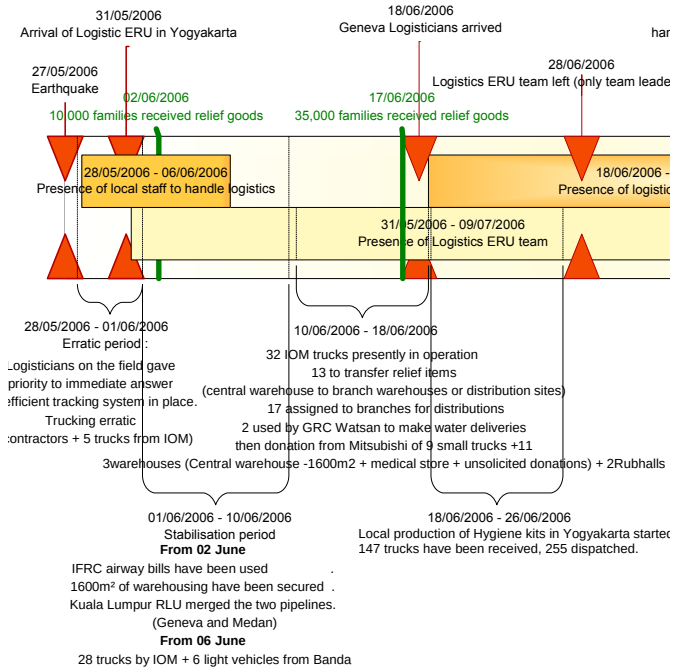


Figure 1.2: Sequence of operations during IFRC's response to Yogyakarta earthquake

6,000 deaths and injuring 36,000 people, while leaving 600,000 homeless and reducing most buildings to rubble. "Yogyakarta's hospitals are already overstretched," Palang Merah Indonesia (PMI, the Indonesian Red Cross) reported. "The electricity and telephone lines have been cut. All of the gas stations are closed, the roads are damaged and two bridges were almost displaced from their concrete bases. Yogyakarta International Airport is out of operation and flights must be redirected either to the Solo airport near Surakarta (60km NE) or to Semarang (120km N)."

A Hectic Four Days

Created in 1863, PMI[7] had a long history of disaster response. The most recent example of this only dated back to the previous month when Mont Merapi, a volcano 70km from Yogyakarta, had erupted. Expecting a larger explosion, PMI had prepositioned stock to respond to the disaster. Leftover stock could then be distributed immediately following the earthquake, providing 1,000 families with essential goods for their survival. Further goods, leftover from the tsunamis which had hit the country in 2004 and 2005, as well as two logisticians, were also deployed from the city of Medan at the onset of the earthquake. "We had already made the invitations to tender for similar equipment for the Tsunami Operation," explained Isabelle Séchaud, an IFRC field logistics officer. "We just extended the contract rather than repeat an invitation to tender, which would have taken much more time."[Sec07]

Very rapidly, news of the earthquake spread. The IFRC sent two logistics delegates to assist PMI, until the arrival of a full logistics Emergency Relief Unit (ERU). PMI and the two logistics delegates found themselves struggling to organize the reception of in-kind donations from all over the world. Although they were in need of many items, such as survival kits, unsolicited

[7] Palang Merah Indonesia (PMI, the Indonesian Red Cross)

donations from other IFRC National Societies as well as from bilateral donors created too much pressure on the local chapter.

In addition to this, while the military raced to complete repairs on the nearest airport, all goods had to be redirected to the Solo airport, 60km away. But when Yogyakarta International Airport reopened, as they got off the plane the ERU[8] had to juggle its already overstretched team to cover both sites. “By the end of the first day, it was already apparent that there were insufficient resources to cover two airports effectively” explained ERU leader Justin Cuckow. He even had to call the IFRC’s Geneva headquarters in panic at 2 o’clock in the morning,asking for additional resources. Later on, an advisory had been sent out to stop use of Solo airport and they had managed to get the situation under control. “Several flights that had already been contracted landed at Solo airport, however, which stretched the team significantly,” Justin added. “Two pipelines, through the Geneva office and at the local level, plus unsolicited donations, made the initial understanding difficult,” he concluded.

At this stage, the RLU[9] in Kuala Lumpur, which should have reconciled these two pipelines, was not yet fully operational. They had no central warehouse and no available stock, and were still training their staff while attempting to provide support to PMI. The regional purchasing system which the RLU was to manage was not fully in place yet; they had as yet established no regional framework agreements for procurement apart from the previously existing global ones created by Geneva and the procurement approval process was still managed entirely there.

However, as the scale of the required disaster response remained relatively small, PMI together with the ERU, Geneva Head Quarters and the RLU in Kuala Lumpur were able to get the operations under control within four days. Within the week following the disaster, the availability of stock, presence of technical staff and the use of sophisticated Humanitarian Logistics Software (HLS) were a clear demonstration of their achievements, which were probably on a par with what would have been expected had the RLU been fully operational from the outset. (see fig 1.2 on the preceding page)

Stabilizing the Supply Chain: the Next Ten Days

By June 2nd, the Kuala Lumpur RLU was in a better position to provide support to the local operations as the situation in the field stabilized. The RLU progressively took the lead in coordinating the logistics aspect of the relationship with donors, which had previously been shared between Geneva headquarters and the local level. Because the RLU was close to the field of operations and could communicate more easily with donors in the same time zone, they were able to limit the number of unsolicited donations by orienting donors as to which needs were still unmet.

Furthermore, the RLU was put in charge of centralizing information about the relief items before they arrived in Yogyakarta. Before, this task was under the direction of the IFRC’s logistics department in Geneva. Because they were so far away from the disaster area and had limited resources dedicated to this, Justin said, “paperwork was unsurprisingly weak. Before the ERU’s arrival, PMI delivery notes were used. They were incomplete and tracking this documentation proved very difficult”. As the RLU took over this function and replaced the delivery notes with IFRC airway bills, documentation and tracking improved considerably.

[8] Emergency Relief Unit, pre-trained teams of experts in specific domains, such as Logistics, Water and Sanitation, IT and Communication...

[9] Regional Logistics Units

They also merged the two pipelines going through Geneva and the local level, which provided better visibility on arrivals and enabled better planning in function of the availability of goods.

While PMI[10]'s warehouse was used for storage throughout the first week of operations, it was too small and the team was constantly worried that it would collapse after having been damaged in the earthquake. After June 2nd, the ERU acquired 1,600m2 of warehousing and progressively took over PMI's inventory. The smaller warehouse was emptied of all but unsolicited donations while medical supplies were stored in a third dedicated warehouse. Having a central warehouse from which they could send relief items directly to distribution sites improved clarity and also allowed the RLU[11] to harmonize tracking and documentation.

Although the benefits of the new approach became clear after each entity appointed a contact person to liaise with the others, it was not initially well received, in particular by PMI. The support role of the RLU was not clear to them, and at first PMI perceived that the RLU had appropriated its prerogatives and mandate. However as time went on, Justin said, staff in the field "recognized a coordinated strategy and the clear management structure in place, as well as excellent cooperation from PMI despite some gaps in staffing". Coordination was eventually perfected, as "all sectoral coordinators were included in the development of the appeal to donors and suitable priority from the outset was given to early recovery," Justin concluded. From Geneva's point of view, the RLU was a success as well, but with a slight damper: the information flows and decision-making process sometimes bypassed them. "In Kuala Lumpur, some people reported to the Pan American Disaster Relief Unit (PADRU) team leader in Panama (which had already been responding to regional disasters before the RLU system was in place), but not to Birgitte" [Sec07]

1.3 Guiding thread 2 - Lessons learnt from past operations

1.3.1 Lessons learnt from Yogyakarta

Faster, better, cheaper

Although the Yogyakarta earthquake was very different from the Indian Ocean tsunami in 2004 or the Pakistan earthquake in 2005, a comparison between the IFRC's performance following the three disasters clearly demonstrates the benefits of the decentralized supply chain through the Kuala Lumpur RLU. It is clear that having local operational capacity such as stock, human resources and infrastructure in place prior to the crisis was invaluable, as was the presence of a local coordinator to manage the pipeline of relief items. This may not always work, however. A look at the 2010 earthquake in Haiti, for example, shows that local capacity in terms of relief items and human resources was in place before the disaster. Yet these resources were located so close to the disaster site that they were destroyed during the tremor. Having local warehouses is also far from sufficient. The items stored must match the needs. In Haiti, for example, shelters and hospitals were set up quickly to look after the victims. As these structures are needed in almost every disaster response, a great deal of work has been done to improve their deployment. MSF (Doctors Without Borders) has even developed inflatable hospitals to facilitate their transport and installation [Wor10]. Yet in Haiti, there were practically no means of action, such as mechanical diggers or shovels to extract people remaining under the rubble.

[10] local National Society
[11] Regional Logistics Unit

Table 1 – Service	Indonesia Tsunam 100,000 families
Families receiving partial package by 2 months	28,021
Families receiving full package by 2 months	0
Average number of families served per day	445
% goods delivered from the region	13%

Table 2 – Speed	Indonesia Tsunam
Days to activate end to end supply chain	18
Order lead time (requisition to delivery) in days	30
% of appeal items mobilized & delivered at 2 months	55%
Average distance of relief items (km) to families	11,805

Table 3 - Cost	Indonesia Tsunam
Operations total costs at 8 months	Not available
% logistics cost (items + transport + storage value)	-
Cost to deliver relief package per family at 2 months	-
Cost to deliver relief package per family at 8 months	-

Figure 1.3: Comparison of the responses to Yogyakarta, Pakistan and Indian Ocean earthquakes, from [Cuc07]

Coming back to Yogyakarta, the decentralized supply chain did result in faster service. According to a study made by an external consultant [Cuc07], the end-to-end supply chain was activated three times faster than in the Pakistan operations and almost six times faster than for the tsunami response.

The decentralized supply chain also resulted in better service. In the tsunami operations or the Pakistan earthquake, after two months the IFRC had only managed to provide partial relief packages to approximately 30% of the families affected. In the Yogyakarta earthquake operations, however, after two months the IFRC had provided at least partial packages to 80% of affected families. In addition to this, all the goods provided were delivered from the region, whereas in the Indian Ocean tsunami this was only the case for 13% of relief items and 68% of those in Pakistan.

The cost of the Yogyakarta operations was also substantially lower. The IFRC declared that "if we had used the Pakistan supply chain setup to respond to the Yogyakarta earthquake, it would have cost around 18 million CHF (a little over €12million) rather than 9 million CHF (a little over €6million) – or we would have been able to assist less than half the families than was actually achieved".(See figure 1.3)

Room for Improvement

Although this was good news for the IFRC, they were well aware that there was still room for improvement within the new supply chain.

Regarding knowledge management, for example, the development of the Humanitarian Logistics Software (HLS) and the Disaster Management and Information System (DMIS) clearly improved timeliness and visibility of relief operations. Indeed, until these became operational,

"each operation was managed with a separate database and record keeping. The Humanitarian Logistics Software had therefore proved its worth in Yogyakarta by tracking relief items as they went through the pipeline. Yet, its use could be optimized in future disaster responses: "consolidation is needed, but this is really difficult," Isabelle confirmed. For example, she further illustrated, items used in the Indian Ocean tsunami had a specific tracking number, but when they were redeployed to Yogyakarta the HLS[12] system gave them a new one [Sec07].

As to redeploying items from one disaster to another, the IFRC[13] also found that they had developed no clear stock replenishment strategy. Justin pointed out that when items from the Indian Ocean tsunami stocks were sent to Yogyakarta, there was no agreement on whether these items should be replaced or not, and if so, at what point and how.

Finally, the RLU's tracking system no longer traced the items once they had gone from the RLU[14] warehouse and had been turned over to PMI[15] and the ERU[16] for distribution.

Although the decentralized supply chain was clearly a success, it was not always clear how to tackle these remaining issues, nor what the implications might be. The wide range of responsibilities delegated to the Logistics Department had completely transformed the IFRC's hierarchy and reporting system. Local staff were now left to face important questions such as "who are our stakeholders and how do we report to them? Who's doing what and how do we link?" While the relationship between National Societies and the RLUs was by now well defined, the National Societies lacked a macro vision of the organisation's structure. Clearly, there was a need for the IFRC to work on updated job descriptions.

At the same time, the RLUs empowered the local level, which could potentially pose a threat in terms of standardization and coordination: "The difficulty lies in avoiding ending up with three small federations," said Birgitte. "As things stand at the moment, Geneva has to be available nearly 24h/24h in order to keep a handle on the situation" [Ols07]

Communications were also a problem, as "they are not read and understood correctly because they are not tailor-made," Birgitte explained. "The RLUs are establishing a monthly report, but it is only the beginning, they are currently working on it. Geneva also insists regularly on the importance of communication and timely exchange of information, and multiplies workshops on this theme." Given these issues, and despite the positive effects of the RLUs, to what extent did the IFRC want to increase their role and importance? While in 2006 the RLUs were authorized to make purchases up to 200,000CHF (€135,000), the goal by 2007 was to double that figure in order to allow better coordination with suppliers. The range of products managed exclusively through Geneva, such as health products, was also to be further limited. And in a second step, the IFRC was considering whether more RLUs would be needed in the long run.

A lot of work still remained for the IFRC if they wanted to garner the full benefit from their new decentralized supply chain. However, after the success of the Yogyakarta response and even before the IFRC received the European Supply Chain Excellence Award, it was evident to all that they had already taken a giant step forward.

[12] Humanitarian Logistics Software
[13] International Federation of the Red Cross and Red Crescent Societies
[14] Regional Logistics Unit
[15] local National Society
[16] Emergency Response Unit

1.4 Latest changes in disaster management

1.4.1 Evolution of disaster management at IFRC

The IFRC had first started to seriously reconsider its traditional supply chain processes in November 1998, when Hurricane Mitch hit Honduras, making it the second deadliest Atlantic hurricane in history. In responding to this crisis, the IFRC took two weeks to start coordinating relief contributions from its National Societies and other donors. As a result, basic supplies were distributed weeks after the hurricane struck and long after other humanitarian organisations had started distributing their own relief items. This event proved to be a catalyst for change within the IFRC, creating both external and internal pressure for the organisation to rethink its supply chain processes. How could they improve the timeliness and relevance of reporting from the field, despite time pressure and a lack of communications infrastructure?

Recognizing the vital importance of logistics

To respond to these issues, in 2002 the IFRC decided to restructure their vertical divisions, give the logistics function a more important place within the organisation, and build its preparedness activities. An IFRC team restructured the Federation into six divisions rather than four. The six new divisions were: Programme Coordination, Disaster Management and Coordination, Knowledge Sharing, Monitoring and Evaluation, Advocacy and Communication. Within each division, a clear distinction was drawn between disaster preparedness and disaster response.

Throughout the organisation, a more important emphasis was placed both on preparedness and on logistics. The IFRC decided to build its preparedness activities around five pillars: Human Resources, Knowledge Management, Operations and Process management, Financial Resources and the Community. This in turn led it to develop a number of standardized tools and processes which could be deployed rapidly in the event of a disaster, such as special guidelines for acceptance of in-kind donations or frame agreements with international and local suppliers on key relief items.

This was also when the IFRC created a Logistics and Resource Mobilization Department (LRMD), which was an important first step in recognizing the role played by logistics and supply chain management in the humanitarian sector, and in disaster relief operations in particular.

An important second step consists in redesigning the supply chain. In IFRC's case, the focus has been made on the decentralization of operational capacity. The following sections illustrate the drivers of the IFRC. The third part of this thesis, dedicated to the design of supply chain under humanitarians' specific conditions will provide a deeper analysis on the motivations to pre-position resources on a local level.

External push for change

The IFRC's traditional donors, be they governments, individuals or institutions, look to it for transparency, effectiveness and efficiency. In the event of a disaster, large numbers of people must be reached as fast as possible; according to humanitarian standards local communities are estimated to be self-reliant only for 48 h, after which humanitarian organisations must be

operational on the ground [TW09]. In fact, they must be operational as soon as beneficiaries' needs arise, given the urgent, even life-threatening nature of these needs. Given their limited resources, humanitarian organisations which depend on donations must provide cost effective interventions as well as rapid ones. Finally, they must provide a high quality of intervention, accessing the maximum number of beneficiaries while responding to as many of their needs as possible. Clearly, the IFRC's operations in Honduras had not lived up to this responsibility. Bad press coverage of the IFRC's intervention during one disaster could have negative repercussions on donations for future operations. In particular, the IFRC was under pressure to demonstrate good performance in comparison to other humanitarian organisations. Failing this, donors could decide to provide disaster relief assistance through other humanitarian organisations rather than supporting the IFRC. National governments might even decide to bypass the non-profit sector and decide to funnel aid on a bilateral basis directly to the governments of affected countries. Concerned by its poor performance, it was at this point that the IFRC had decided to take a closer look at its humanitarian supply chain.

Internal push for change

The pressure for the IFRC to reform following Hurricane Mitch was reinforced internally as well as externally, ensuring that the process would not lose its momentum. If donors were dissatisfied with the IFRC's response to the hurricane, the National Societies were even more so, and expressed their disappointment by sending no fewer than 22 reports to the IFRC on its performance in Honduras. In the event of a natural or man-made disaster in their home country, NSs[17] need to be able to call on the IFRC to assist them in their operations through a range of support mechanisms. In particular, the IFRC is supposed to help NSs to coordinate the supply chain for donations of relief items from other NSs and donors worldwide. The NSs argued, however, that in the Hurricane Mitch operations the whole range of support instruments that the Federation was supposed to provide had failed them. Support teams, technical staff and relief delegates had been deployed too late, no supplies had been pre-positioned and it had taken weeks before the IFRC was in a position to coordinate appeals for goods or incoming donations. As a Federation of 186 National Societies, the IFRC is far from a commercial 'command and control' supply chain model. Each NS has its own priorities and all are autonomous and responsible to their own national stakeholders. When the Honduras operations demonstrated the inadequacy of the IFRC's supply chain, NSs pressured the Federation to reduce the concentration of power within the Geneva headquarters and restructure the supply chain closer to the individual countries and regions by building more capacity at the local level. This internal push for change met with a positive reaction and full support from Didier Cherpitel, the IFRC's Secretary General from 1999 to 2003, and later on from his successor Markku Niskala.

Launching the New and Improved Decentralized Supply Chain

The IFRC made a big step toward improvement in 1999 when they decided to create the Pan American Disaster Response Unit (PADRU) to pilot the idea of developing a decentralized operational capacity for disaster preparedness and response. By 2001, PADRU was engaged in assisting National Societies throughout Latin America and the Caribbean in responding to floods, earthquakes and hurricanes. Its role was to "provide support to National Societies in

[17] National Societies

coordination with the regional delegations through coordination, personnel, logistical support and leadership, as appropriate". This proved at times to be a delicate task. Convincing a National Society to sign off on pre-determined agreements was not a straightforward job for PADRU staff. "We always have to remember that NSs are independent organisations. They may or may not follow our advice," an operation manager pointed out.

The idea of decentralizing the IFRC's operational capacity through multiple Regional Logistics Units modeled on PADRU[18] was already being circulated within the organisation by 2003. On the one hand, the idea was risky as it implied great changes and a number of challenges could be foreseen. The pool of IFRC knowledge on supply chain management was in Geneva. Standardization was already difficult, so what would happen with a decentralized system? Furthermore, the relationship with stakeholders was built in Geneva. Delocalizing them might endanger these partnerships. On the other hand, the initial experience with PADRU had had demonstrable results. Implementing a decentralized supply chain could be an opportunity to "combine the knowledge and professional strengths of Geneva with local understanding of the field". Weighing the pros and the cons, the IFRC decided take up the challenge.

The 2005 Logistics Conference in Dubai served as a launching platform for the IFRC's decentralized supply chain plan. There, the IFRC logistics department committed to a program of work centered around two main goals, "to improve customer services by getting nearer to the field" and " to try to reduce the fact that National Societies still enter the supply chain as parallel systems" [Ols07]. Concretely, Birgitte's team was to set up three Regional Logistics Units as well as a set of tools and processes to enable better coordination and a quicker response, at a cheaper price.

Once this process was set up, the logistics department would then assume responsibility for the overall strategy, management and funding for all global logistics activities. Some specialized areas would however remain under the control of central management in Geneva.

As for the 3 RLUs, they would be tasked with delivering mobilization, procurement, stock, warehousing and fleet services within their respective geographical region. The goal was that each RLU should be able to feed 5,000 families within 48h and a further 15,000 families within 14 days. Together, these RLUs should have the capacity to respond to the needs of 34,000 families in the event of a disaster.

Lessons learned

This 10-year retrospective of the changes in disaster management within the IFRC illustrates the validity of supply chain principles within the context of humanitarian operations. Decentralization, pre-positioning and pooling of relief items, for example, resulted in dramatic improvements in the IFRC's performance in disaster operations, in particular during the Yogyakarta earthquake in 2006. However this case study also demonstrates the difficulty of implementing an improved supply chain design within humanitarian organisations, given conditions of uncertain command and control, multiple decision centers within a federative context of 186 independent members, and precarious funding. The change process must be supported by standardized items and processes, traceability through adapted information systems, and the right set of skills among staff.

The evolution of the IFRC's supply chain provides some valuable insights as to how global supply chain excellence can be attained within the complex and uncertain context of humanitarian organisations through an application of fundamental supply chain principles.

[18] the Pan American Disaster Response Unit

However, there are undoubtedly both organisational and operational limitations to this type of application, which further research could explore.

On the one hand, it is not clear whether the supply chain restructuring process around a decentralized model would be appropriate in all organisational contexts within the humanitarian sector. The IFRC is somewhat unique insofar as it is a very large organisation which operates on a global scale through a very specific federative arrangement grouping independent NSs. Not all humanitarian organisations would have the resources to either justify or implement a decentralized supply chain. This specific problem will be explored in the third part of this thesis.

On the other hand, whereas a great improvement in terms of effectiveness and responsiveness was clear in the specific context of Yogyakarta, the various factors involved in this achievement are not all explicit. What is the exact role of the decentralization of the supply chain is this success ? What are the methods, the processes that have reinforced IFRC's ability to respond quickly and adequately to disasters ? This will be studied in the second part of this thesis.

1.4.2 Humanitarian Reform in 2005

The context of humanitarian aid has strongly evolved over the past ten years. The change is obvious in the IFRC, as we have seen in the previous sections. Other humanitarian stakeholders have also considerably changed the way they work during and between disasters. The following sections provide an overview of recent changes in disaster management that have been implemented by other major humanitarian stakeholders, such as UN agencies.

Figure 1.4: Humanitarian Reform

In 2005, The United Nations Emergency Relief Coordinator, Jan Egeland, asked four independent consultants to identify the factors that have hindered the speed and effectiveness of humanitarian responses in the past and to propose appropriate steps to improve the timeliness and impact of future humanitarian interventions [UNO05a]. Their main findings are summarised in table 1.4. This lead to the 2005 Humanitarian Reform. Its aims are as follows:

- Strengthening of response capacity: the Cluster Approach

  The response is organised by sector or area of activity, each one having its cluster leads well-identified on a global level. At the beginning, eleven sectors were defined, such as Camp Coordination and Logistics, as well as Agriculture, Education and Early Recovery. For each emergency, different local clusters leads are chosen.

- Better humanitarian financing: the Central Emergency Response Fund (CERF)

  The first part is a cash-flow mechanism. US $50 million are available in total, loaned to provide quick access to funds instead of waiting for donor pledges to be transferred. This amount must be reimbursed within 6 months. The second part is a stand-by fund, up to $450 million, granted for rapid response and under-funded emergencies. CERF is intended to complement, not substitute, existing funding mechanisms. It cannot fund preparedness, mitigation or prevention activities. It also funds mainly UN Agencies.

- Strengthening of the humanitarian coordination system : Resident Coordinators (RCs) and Humanitarian Coordinators (HCs)

  The aim of this system is the creation of a pool of human resources equipped with the right skills and experience and the development of a Score Card. It is still under development.

Table 1.4: Weaknesses and threats underlined by the Humanitarian Response Review before implementation of the 2005 Humanitarian Reform ([UNO05a] and [UNO05b])

Weaknesses	Threats
Well-known, long-standing gaps in the response	Proliferation of humanitarian actors
Insufficient accountability (particularly for the response to IDPs[19])	The changing role of the UN (more "outsourcing" to NGOs)
Inconsistent donor policies	The competitive funding environment
Limited linkages between UN and non-UN actors	Increased public scrutiny of humanitarian action
Erratic coordination, dependence on personalities	

Most of the UN community agree that the reform's implementation constitutes an improvement, but many others consider many challenges to be remaining. The competitive funding environment, focussed on the response phase instead of on long-term, more sustainable improvements, remains a major issue [JH08]. The use of local NGOs and cluster partners is also far from systematic [UNO05b] and therefore remains a challenge. Change management is never easy, and in this case, many NGOs, whether local or international, felt disregarded or decided to bypass this new organisation proposed by the United Nations (see table 3). And those who accepted this reform still lack a rationalised coordination structure. Clusters were hampered by many problems. Meetings lacked full attendance, and operational and field staff were located at hub clusters, while decision-makers, such as the heads of agencies, were in Islamabad, a problem compounded even further by communication problems between hubs and clusters [Int06].

Best practices exist, but the management of this knowledge is still dependent on the presence and training of local capacity. "In Union of Myanmar, a dedicated Information Manager has been appointed and a web based information management system has been developed, enabling agencies to search and access relevant information for the response, including digitalized maps showing operational agencies by geographical area" [BL08]. Yet, many reports for other emergencies pinpoint the "need for adequate IM[20] tools and services to support the approach" [UNO05b].

1.4.3 Other initiatives to improve management of relief operations

In the field

The diversity of stakeholders and the variability of their presence and strength from one disaster to another makes it extremely difficult to generalise best practices in terms of disaster

[19] Internally Displaced People. Those who had to move within their own country to find safety and refuge.
[20] 'Information Management

Table 1.5: Fieldworkers' feedback after implementation of Humanitarian Reform ([UNO05b]; [Int06]; [THW08])

PROs	Neutral	CONs
"At this stage we don't have a better way to do things" Nicholas Palanque, country director for CARE International in Chad	"Personally, I still don't really know what the practical difference is between the new cluster system and the former system" Jef Imans, head of the International Rescue Committee (IRC) in Chad	"The clusters are nothing more than a way for the UN to control us" one aid worker at Action Against Hunger (AAH) in Chad
"I don't think anyone can deny that cooperation between technical coordinators has improved" Nicholas Palanque, country director for CARE International in Chad	"It is certainly not a bottom-up driven process" Christophe Droeven, head of Catholic Relief Services (CRS) in Chad	"It's a lot of work and energy. In the end you have to make the decision, is it better to attend the meeting or actually do our jobs?" Thomas Merkelbach, head of the International Committee of the Red Cross (ICRC) in Chad

response. Fortunately, if we consider only humanitarian organisations offering the same range of products and services and having a shared initial intent, many initiatives have been developed to improve the management of relief operations. They realise that "in a world of scarce resources, although humanitarian action has no price, it obviously has a cost" [CP10], and an improved management of this cost has an influence on the ability to send relief to a varying number of operation sites.

Among possible savings, the best logistical coordination plays a significant part, for example in trying to avoid useless equipment or food redundancies in one place when a few miles further, both are sorely lacking [CP10]. Such successful collaboration networks on a local level often include local partners. Because they know the local customs and networks, and because they are highly knowledgeable about the local environment, locals are in a position to complement international staff. These implementing partners can be local NGOs or local companies with an existing network and trained resources.

During the 2006 Lebanon conflict, Agility, a logistics company, was a major stakeholder. "We had decided that we were going to provide in-kind services in the form of transportation and warehousing, and also offer the expertise of some experienced operational managers to humanitarian organisations, since we knew that the logistics landscape of Syria and Lebanon would be unfamiliar to many humanitarian actors" [THW08]. In such environments, local knowledge is essential. "The minute something happens, you see, you listen... you are used to working with difficult, uncertain and constantly changing conditions" [THW08]. With a turnover of 80% per year, international NGOs have limited trained resources. Local implementing partners are therefore often very useful. Yet their presence and strength vary from one disaster to another. The collaboration networks vary accordingly, which will be further analysed in section 2.8 on page 27.

In addition to these improvements in terms of organisation and collaboration, more and more tracking and measurement systems are being used. The Humanitarian Logistics Software used by the IFRC is one example of the major improvements made recently with the introduction of standardised tools and procedures. As we illustrated with the Yogyakarta Case Study, having

such systems in place helps significantly in terms of velocity and visibility.

At a global level

More and more stand-alone initiatives are giving birth to global collaboration networks aimed at improving the management of disasters. The Global Humanitarian Platform, for example, was created in 2006 to strengthen partnerships among humanitarian actors. The Red Cross and the Red Crescent movement, NGOs and UN agencies, are thus meeting once a year to increase their transparency and complementarities. We can also add more dedicated group meetings, like the Inter-Agency Procurement Group or the Fleet Forum. These meetings assemble practitioners to share best practices and align their efforts on key improvement areas, such as procurement or fleet management. Here again, academics working on those specific subjects could be helpful. Increasing numbers of partnerships between humanitarian organisations and private companies are also being developed. Many case studies illustrate such successful approaches (See [THW08]; [TW05a] [Was06a] and [TW09] among others).

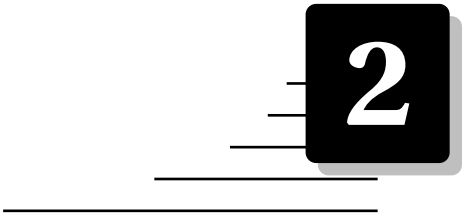
Such collaboration networks are usually formed when stakeholders realise they have much to learn from each other. This illustrates the fact that donations to humanitarian organisations can take many forms. It can be financial support or in-kind donations, or even knowledge transfers. The latter kind of partnership often benefits both sides. TNT[21]'s involvement with WFP[22] is one example of logistics management (see figure1.5). Roche giving license to use its licensed process to produce tamiflu[23] is another. See [UNO05b] for detailed examples of such partnerships.

More recently, partnerships have begun to include other actors, such as governmental agencies like the Centre National d'Etudes Spatiales (CNES) and also academic partners. One of these public-private partnerships is Huma-Nav. It aims to develop a dedicated service for humanitarian fleet management, allowing partners to share information on mutual experiences and existing initiatives [Was06a]. These are a few chosen examples of collaboration networks involving humanitarian organisations. Many others exist, including other actors such as donors or suppliers. "Such partnerships are interesting, challenging and rewarding… but really difficult sometimes. It is essential to choose the right partners and find the optimal number of actors" [Wor10].

Figure 1.5: TNT / WFP - Moving the World
One example of a successful partnership between a UN agency and a private company

Reports on lessons learnt or on performance measurement are also becoming more frequent and illustrate the movement of organisations toward better transparency and accountability, as well as their achievements in terms of effectiveness. Organisations have also started many initiatives to better understand and predict humanitarian demand, and in addition to this, they are sharing their findings with one another. They are also reflecting on the design of their distribution systems.

[21] TNT is a Dutch company, working in the business of transferring goods and documents around the world.
[22] World Food Program
[23] the most frequently prescribed medicine for flu treatment and flu prevention



Salient features of humanitarian supply chains

Introduction - Many characteristics

Various approaches and definitions ([SK02]; [Men+01]; [AC04]) consider Supply Chain Management (SCM) to be coordinated systems for managing flows. [CE93], for example, define SCM as "an integrative philosophy to manage the total flow of a distribution channel from the supplier to the ultimate user".

Simchi-levi specifies that SCM is "a set of approaches utilized to efficiently integrate suppliers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements" [SKS03].

If we exclude some unsuitable terms such as "customer" or "store", the concept of SCM[1] explains what humanitarian organisations, suppliers and donors should do to minimise the impact of crises. This concept, applied to disaster relief, is called the Humanitarian Supply Chain (HSC).

According to Van Wassenhove, HSCs[2] are about 15 years behind their private sector counterparts, who long ago realised the importance of using efficient supply chains [Was06b]. He also explains that humanitarian logisticians have been struggling for recognition and that humanitarian organisations are just beginning to become conscious of the fact that logistics are crucial. Indeed, although the effectiveness of the supply chain is a critical factor in the performance of humanitarian relief organisations, this sector has been slow to make much-needed investments in logistics [ins05].

While the humanitarian world has now become aware of logistics, work in the context of natural or man-made disasters is very different from logistics in the business context. Several authors ([Nat91]; [Bea04]; [Ste06]; [KS07]; [Olo07]) have tried to identify the characteristics of its particular context. We have retained seven different categories:

[1] Supply Chain Management
[2] Humanitarian Supply Chains

1. The humanitarian operation life cycle and the dynamics of operations
2. The humanitarian space
3. The stakeholders
4. The categories of flows managed
5. The funding process
6. The dynamics
7. The uncertainties

2.1 The humanitarian operation life cycle

If we consider a project to be a temporary endeavour undertaken to achieve a particular aim, then HSC[3] operations can be deemed a project. In fact, humanitarian organisations are responsible for producing relevant output and hence they must be constantly aware of the project goal (minimising the impact of a crisis), project purpose, and of course, internal measures for project management efficiency. Concretely, there are two kinds of project environments for implementing humanitarian logistics operations (see Chapter 1 on page 3):

- Slow-onset disasters:

  In this case, the focus is on capacity building, using national staff, cost savings, low budgets, planning and scheduling, and long time frames.

- Sudden-onset disasters:

  In this case, the focus is on providing medical assistance, providing food and non-food items, launching appeals, globally assessing needs, using international staff, high budgets and very short time frames.

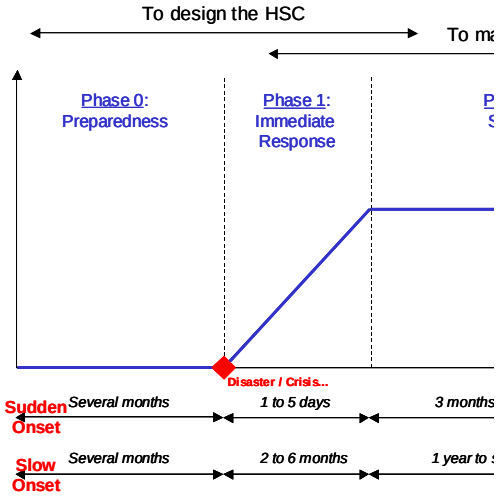


Figure 2.1: Disaster management phases / Humanitarian Operation Life Cycle, from [Tho02]

[3] Humanitarian Supply Chain

The Figure 2.1 distinguishes the four different phases that describe the life cycle of a humanitarian operation (inspired from ([PB05];[Tho02]): Preparedness, Immediate Response (Ramp up), Support (Maturity) and Dismantling (Ramp down). The duration of operations varies according to the function of the project characteristics (sudden- or slow-onset). Despite these variations, the duration is much less important than in any comparable industrial project. (see Figure 2.1)

2.2 Humanitarian space

Humanitarian organisations live by their principles of humanity, neutrality and impartiality. In other words, they should help everyone in need wherever found; should not influence the outcome of a conflict with their intervention; and should not favour one group of beneficiaries over another. These principles define the 'space', both physically and virtually, in which they need to be able to operate to do their job effectively [TW09].

These principles add many constraints on humanitarian supply chains, especially when they operate in politically volatile areas. In case of conflict, for example, the same amount of relief items has to be distributed to each side, at the same time. The supply chain has to be carefully designed to enable this simultaneous distribution.

2.3 Stakeholders

The humanitarian distribution channels go through many different stakeholders - called Strategic Humanitarian Units (SHU) - starting from suppliers to beneficiaries (but not consumers or users). These SHUs are made up of diverse groups of stakeholders: UN agencies such as the World Food Programme (WFP), international non-governmental organisations (INGOs) such as World Vision International, smaller non-governmental organisations (NGOs), implementing partners such as local NGOS or private companies, the army, local or not, donors such as private companies or governments, again, local or not, and, at the end, the beneficiaries.

Figure 2.2 gives an overview of their various natures and interactions.

All these SHUs have more or less of the following properties:

- Under-resourced, limited skills availability and high employee turnover (80% annually according to [TK05]), which limits institutional memory and efficiency
- Ineffective leverage of technology (non-robust equipment, for example) and in particular, information systems that are relatively basic. Many relief logistics departments rely on manual systems without any Information Technology
- Command and Control lacking
- Several operations are done at the same time

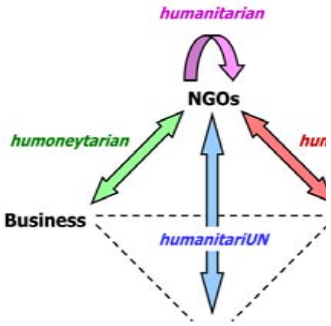


Figure 2.2: Stakeholders and types of relationship (from Larson, private communication)

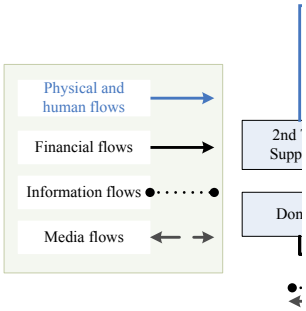


Figure 2.3: Overview of flows managed in an HSC, of major stakeholders and their position within the supply chain

In addition, not all stakeholders have the same incentives or the same way of operating. This will be further analysed in the following chapters.

2.4 Categories of flows managed

The humanitarian distribution channels manage the traditional categories of flows, but these present some specificities (see figure 2.3)

- Physical flows are material (food, items, etc.) and human (response teams, etc.)
- Informational flows (order transmission, tracking and coordination of physical flows) are poorly structured and managed; less than one fourth of logisticians have access to a proper tracking system [TK05].
- Financial flows are unilateral (from donors to beneficiaries).

Regarding information flows, the role played by the media is incredibly strong in humanitarian supply chains. It directly impacts the size and the complexity of the relief operations. With no media coverage, the number and commitment of donors, and therefore the number of items transiting the supply chain, tends to shrink. On the other hand, over-exposure leads to overreaction of donors, which creates imbalances between the amount of items sent and the amount of resources available to manage them. It also often leads to a higher level of unsolicited items, which get in the way of relief operations and hinder the actual delivery of aid. In addition, after a disaster, local means of communication are often reduced, with scarce Internet access for example.

2.5 Funding process

HSCs[4] are financed by donors (governments, companies, private industries, etc.) through a funding process. The funding process is a channel for donations from individual people, private companies, governments or donor organisations to the beneficiaries through several SHUs[5].

[4] Humanitarian Supply Chains
[5] strategic humanitarian unit

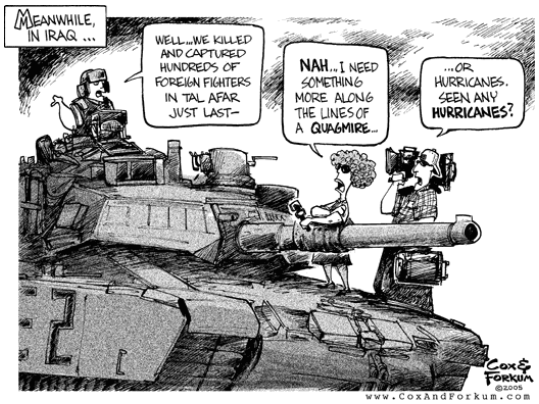


Figure 2.4: Media impact - the bigger the crisis, the wider the media coverage and the resulting number of donations, which leads to a lack of funding for frequent small disasters

The donations can take various forms. They can be cash or in-kind donations. The latter can be relief items for means of action, but can also be human resources or knowledge transfers. Donations can be a long-term engagement, like Moving the World between TNT[6] and WFP[7] or membership dues, but they can also be sporadic and/or dedicated to a specific operation. To respond to the Indian Ocean tsunami, for example, NGOs[8] raised massive amounts funds thanks to widespread media coverage and the involvement of telephone companies, for example. In the latter case, donations could be made by sending an SMS to a specific number, which is a clear and easy way to involve large numbers of donors.

Contrary to Commercial Supply Chains, financial flows for humanitarian actions are not directly proportional to or parallel with material flows. The amount, nature and use of donations depend on donors' good will, which is sometimes not well-aligned with real needs. For example, donors usually focus on disaster response as it is more visual and attractive (see figure 2.4). Although necessary, this does not take into account humanitarian organisations' need to build in preparedness. Many practitioners estimate that one dollar invested in preparedness is worth more than three dollars spent in response. Yet as the results are more difficult to measure and the return on investment much longer, funding of preparedness activities is still remarkably low. Another consequence of this funding process is the presence of numerous underfunded emergencies that NGOs have difficulty responding to as they cannot always choose the way they spend the resources they receive.

This is a well-known gap in disaster management that has received a lot of attention lately from various SHUs. The funding of "forgotten" emergencies has been improved thanks to the reform of the UN's CERF[9] for example (see previous chapter).

2.6 Dynamics

The dynamics of an HSC are very specific because they try to respond to certain vital needs. These dynamics are exacerbated in the case of sudden-onset disaster, where needs arise suddenly after the occurrence of the crisis. An HSC does not start with a customer expressing

[6] Dutch transportation company
[7] World Food Program
[8] Non-Governmental Organisations
[9] United Nation Common Emergency Response Fund

needs and does not want to maximise profits. Under these conditions, is quite difficult to apply best practices in terms of planning and scheduling. There is evidence of a frequent lack of planning in relief supply chains, resulting in inefficiencies. These include the overuse of expensive and unsafe air charters, failure to pre-plan stocks, congestion at ports caused by unplanned deliveries, delivery of useless or unwanted items to disaster victims and a lack of inter-organisational collaboration for information systems [Was06b]. Most of the time, an SHU[10] generally has to:

- Assess needs, urgent and vital, but also uncertain
- Coordinate supply, also urgent and uncertain
- Work under emergency conditions, consider unforeseeable events and work within extremely short timelines
- Take into consideration the lack of transparency and the volatile climate in which humanitarian organisations may have to operate

2.7 Uncertainty, complexity - Definitions and importance in our specific context

This high level of uncertainty in terms of demand, supply and environment bring many constraints on managing the HSC. A fundamental characteristic of humanitarian supply chains is the omnipresence of uncertainty. "In disaster emergency response situations important attributes of the problem are uncertain (e.g. its nature, scale, time, etc.). The problem environment is changing rapidly and uncontrollably. There is very little time for making a decision but information might not be available (or, even if available, might not be reliable)" [AG05].

As for other phases of disaster management, they also have their share of uncertainty. The fact that humanitarian organisations are linked to their sources of supply and funding by moral rather than legal agreements increases the risk of supply or funding rupture. As for demand, though you may have an idea on the most vulnerable places, it is difficult, if not impossible, to foresee where the next disaster is going to strike. You do not know which stakeholders you will have to work with, either. [Gas94] also points that "public sector problems are generally ill-defined, have high behavioral content, and are overlaid with strong political implications", which increases complexity, and thus uncertainty.

From a more theoretical point of view, according to [DP06], uncertainty has two origins. "It may arise from randomness (often referred to as "objective uncertainty") due to natural variability of observations. Or it may be caused by imprecision (often referred to as "subjective uncertainty") due to a lack of information" [BD05]. Regarding the latter category, to be more accurate, we have to complement their definition of subjective uncertainty. Indeed, lack of information is only one of the multiple sources of subjective uncertainty. According to Dubois and Prade [DP06]; [Bel08], uncertainty comes from imperfect information, which can be distinguished as:

- Uncertainty, which refers to the truth of information. It characterises its degree of conformity with reality.

[10] strategic humanitarian unit

- Imprecision, which concerns the information's content and indicates its quantitative defect of knowledge.
- Incompleteness, when information about some aspects of the problem is lacking.
- Ambiguity, when the information can be interpreted in different ways.
- Conflict, when many sources of information lead to contradictory and incompatible interpretations.

As we have seen in the previous chapter, humanitarian supply chains are project-oriented. If we refer to [LDP06], there are four sources of project uncertainty:

- Foreseeable uncertainties, which correspond to the above-mentioned uncertainties.
- Residual risk, or "what is left over after planning for foreseeable uncertainty" [LDP06]
- Complexities
  - Detail, or combinatorial complexity, which arises when decision makers must consider a large number of components or possible combinations in a system before making a decision [Ste94].
  - Dynamic complexity, which arises from the subtle and delayed cause-and-effect interactions of system agents over time [Ste94].
- Unknown unknowns, "those that do not have a definite formulation, have no stopping rule that allows one to determine when the problem is solved, where solutions cannot be fully tested and the problem cannot be generalized, and where there is ambiguity about problem causes" [LDP06].

Each of these sources is present in the humanitarian world. Every day, in many countries, humanitarian workers face uncertainties, foreseeable or not, with regard to demand and supply; they face the complexity of the environment due to the politically volatile climate, the damage suffered by local infrastructure, the multiplicity of stakeholders having various incentives, and so on. They also face unknown unknowns, where the situation is so confusing that the issues are difficult to define.

2.8 Differences with the private sector

If you consider the usual definitions of a supply chain (see section 2 on page 21), you can see that the notion of "customer" plays a significant role. Yet within humanitarian organisations, there is actually no consensus about the acceptance and clear understanding of the notion of customer. A customer, in a commercial supply chain, pays for the product or service he uses. In the humanitarian world, the end user, or beneficiary, is a different entity than the buyer, or donor.

Similar comments can be made upstream of the supply chain. Two kinds of suppliers may be found, the ones that give products or money, or donors, and the ones that are paid by the organisation to supply what is necessary.

Another major difference lies in the shelf life of each supply chain. Relief chains are project-oriented. They have a short shelf life and are set up under specific conditions, thus facing more uncertainties. They therefore require a high agility level. The actors involved may vary from one operation to another. Organisations, donors, suppliers, and of course end users, are linked only episodically, which makes mutual understanding much more difficult to achieve.

As we have seen in this chapter, the categories of flows managed is one of the specificities of humanitarian operations. A final comparative element is therefore the nature, size and direction of the flows in each supply chain. There is no closed-loop supply chain, as victims usually don't complain or return the products they have received. Human and knowledge flows are more important in HSCs[11], as is the impact of the media. The financial flows are also much more difficult to manage, as the amount of money received doesn't always match the amount of resources needed. (see section 2.5 on page 24)

All these elements make the notion of a supply chain slightly different from one sector to another. Table 2.1 on the next page summarises these differences and their impacts.

2.9 Difficulties of the HSC - The problem of coordination

Lack of coordination has often been listed as a major weakness of humanitarian operations [TW03]; [Ste05]); [Ken04] and [Mul02]). This issue has received a lot of attention lately in the humanitarian field, such as the 2005 humanitarian reform and its major achievement, the cluster approach. (see section 1.4.2)

This way of operating has shown its limits. According to humanitarian workers, "the coordination system that has generally been put in place tends to take a 'silo' approach to response, with sectors/clusters looking at issues that then (should) feed into a broader coordination process. Over the years, as a result, gaps have been identified in the approach – gender, HIV/AIDS, the elderly, etc. – with guidelines and task forces created to try and fill those gaps. [...] While each of these gap areas rightly requires a response, the result is a more 'congested' coordination field with a myriad of guidelines and task forces at the global level and numerous meetings at the field level. This system makes it difficult to ensure that there is an adequate shared analysis of the overall needs and vulnerabilities to be addressed by humanitarian actors" [VAI08]. Furthermore, as humanitarian supply chains have a short shelf life, a volatile environment and a wide diversity of stakeholders (see chapter 2 on page 21), coordination can take many forms. Coordination is difficult to achieve and often listed as a major weakness of humanitarian supply chains [KS07].[Wor10].

This section is aimed at a better understanding of the difficulties of managing HSCs.

To this end, we will first clarify what we call coordination in a humanitarian context. Indeed, there is actually no consensus on a definition of coordination that would be applicable to supply chains in general, much less in the specific context of relief operations. We will then illustrate and highlight the fundamental barriers and enablers of coordination in relief operations.

2.9.1 Horizontal coordination

At a local level, we call a collaboration network "the system-wide structure of inter-organisational coordination during humanitarian operations" [MED03]. [Don96] has identified three cate-

[11] Humanitarian Supply Chains

Table 2.1: Main differences between humanitarian and commercial supply chains

	Commercial Supply Chain	Humanitarian Supply Chain	So What?
Supply chain range	From supplier's supplier to customer's customer	From donors and suppliers to beneficiaries	Production of goods doesn't apply to humanitarians. Focus in this thesis is on end users, not donors.
Customer definition	End user = Buyer	End user (Beneficiary)≠Buyer (donor)	
Shelf life	Some years, but tends to shorten	Some weeks to some months in total, mounting and dismantling included. Project-oriented.	Best practice transfer needs validation of relevance as per business case, but it fits with the trend toward shorter life cycles of products
Information flow	Generally well-structured.	High importance of the media; means of communication often reduced (no Internet access in field, etc.)	Visibility is more difficult to achieve for HSC
Human flows		People flows + knowledge transfer	
Financial flows	Bilateral and known	Unilateral (from donor to beneficiary) and uncertain	
Actors	Known, with aligned incentives	Multiplicity in nature, but scarcity in numbers + misaligned incentives	High level of uncertainty for HSC, so higher level of agility required. Best practice transfer needs validation of relevance as per business case.
Supply	Suppliers generally known in advance.	Supplier and/or donor uncertain	
Demand	Usually forecast / known	Uncertainties	
Environment	More and more volatile	Highly volatile and unstable	

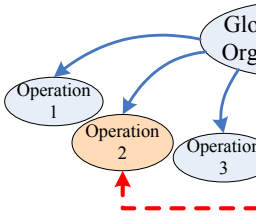


Figure 2.5: Horizontal coordination

gories of coordination in this context:

- Coordination by command where there is central coordination; agreement on responsibilities and objectives; and common territorial areas of responsibility.
- Coordination by consensus where organisations have access to compatible or shared communications equipment, liaison and interagency meetings and pre-mission assessments.
- Coordination by default includes routine contact between desk officers and civilian and military operations centers.

Figure 2.5 shows a simplified picture of the usual collaboration modes and figure 2.6 illustrates their use in various phases in the disaster management life cycle.

During relief operations, there are many participants in the field without a clear division of work [Bym00]. In addition, communication between stakeholders is far from optimal. It is easy to understand that two stakeholders having different incentives will have difficulties sharing information.

On the other hand, two stakeholders having the same principle activities should be able to align their operations in order to ensure a proper distribution of aid. And yet, a survey of logisticians who participated in the tsunami relief operations showed that "just over half the logisticians (56%) reported working with other agencies in setting up their supply chains" [TK05]. All these factors contribute to complexity in the delivery of relief.

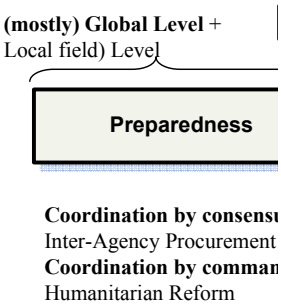


Figure 2.6: Disaster phases and collaboration modes usually associated (Inspired by [TW09] and [Don96]

Figure 2.7: Local NGOs and smaller stakeholders are sometimes disregarded

The following sections will provide an overall analysis of various barriers and enablers in the implemention of collaboration networks involving humanitarian organisations. The analysis is based on case studies and practitioner interviews. The existing literature, mainly the articles which are case-study oriented and NGO reports, also facilitated this analysis.

2.9.2 Barriers and enablers of horizontal coordination during the response and recovery phase

The fact that the nature, the number and the incentives of stakeholders varies from one crisis to another, whether international NGOs or local implementing partners, is an initial element limiting the possibility of having a clear collaboration framework to use wherever disaster strikes. The locals, vital for the distribution of aid, vary widely in their ability and willingness to partner international aid agencies. They are also often disregarded, as they do not have the capacity to participate in all coordination meetings. (See figure 2.7)

The actual tools and methods for structuring relief efforts are also far from sufficient for establishing a clear and systematic process of choosing and implementing the best collaboration process. Trained human resources and adequate IT[12] tools for managing operations, collecting data and thus enabling humanitarians to better prepare future operations are still lacking, though these issues have recently received a lot of attention, both by practitioners and by academics. Table 2.2 summarises the main barriers and enablers of horizontal coordination during relief efforts.

2.9.3 Barriers and enablers of horizontal coordination during the preparedness phase

Once again, the fact that the nature, the number and the incentives of stakeholders varies from one crisis to another, whether international NGOs or local implementing partners, limits the possibility of implementing horizontal coordination processes.

Common humanitarian organisations, though they share the same humanitarian principles, may be reluctant to partner with each other. The neutrality and impartiality imposed by the humanitarian space (see [TW09]) has made MSF (among others) refuse to work with governments, and sometimes also with UN agencies, for example. It is therefore difficult, if not impossible, for them to have formal coordination processes with hierarchical links that

[12] Information and Telecommunication

Table 2.2: Barriers and enablers of the implemention of collaboration networks involving humanitarian organisations on a local level, inspired from [THW08]; [TW09]; [Wor10]; [Int06] and [Ste06]

Barriers	Enablers
In-country NGOs vary widely in their ability and willingness to partner UN or international NGO bodies	Most organisations are connected to one another in principle through their desire to provide aid effectively
Most organisations are associated with each other only episodically	General awareness of the aims and competencies of principal actors
Accurate data for needs assessment, logistics management and many other critical parts of operations is vital but typically difficult to obtain	Specific shared IT tools are being developed to improve data capture and analysis
All humanitarian organisations are poor in lessons learnt and need structure to prepare know-how, knowledge rules/pools, and to clarify what they need in specific fields	Score cards are under development in most major international NGOs
The humanitarian community has many serious weaknesses in managing human resources, from recruitment to training to appraisal	

would require them to report to governmental agencies or other humanitarian stakeholders. Similar issues can also be faced between actors who, at first glance, do not appear to be very different. The French Red Cross and the IFRC, for example, share the same name, but that doesn't mean that they accept clear reporting lines. As for the existing reforms, they are aimed

Table 2.3: Barriers and enablers of the implemention of collaboration networks involving humanitarian organisations on a global level, inspired from [TW09][Fau09]and [BL08]

Barriers	Enablers
Lack of mutual understanding due to the diversity of actors	Choice of the right ecosystem of actors
Lack of transparency and accountability	Incentives for shared information on mutual experiences and existing initiatives
Insufficient commitment at all levels	Involvement of key actors of the value chain
Lack of clarity on roles and responsibilities	Development of clear and jointly agreed roles and responsibilities for encouraging commitment of actors
Lack of change management	Participatory approaches
Lack of funding for activities that have no direct, visible and dedicated field application	Support of adequate Information Management tools and services

at creating better humanitarian coordination (see section 1.4.2 on humanitarian reform), but they encountered many issues during their implementation. Most of the arguments against them were to underline the top-down approach and the lack of change management accompanying reform. The design and implementation of coordination processes is also time-consuming. As preparedness activities, such as this work on coordination processes, lack visible impact, they also lack funding from donors, which does little to reinforce organisations'

commitment. Table 2.3 on the preceding page summarises the main barriers and enablers of horizontal coordination on a global level.

2.9.4 Helping choose an adequate collaboration mode

"Each State has the responsibility first and foremost to take care of the victims of natural disasters and other emergencies occurring on its territory. Hence, the affected State has the primary role in the initiation, organization, coordination, and implementation of humanitarian assistance within its territory" [Nat91].

After a disaster in the field, collaboration networks involving humanitarian organisations have to include local governments. It is their ability and willingness to take the lead or not that shape the global humanitarian relief effort. Then, the strength of the local capacity comes into consideration. "If trained resources and adequate means of actions are already ready to be deployed, they should be and usually are involved from the beginning" [Wor10]. These are some elements that illustrate the difficulty in having a pre-defined response model to implement no matter where or what the disaster is.

The responses to the 2008 Sichuan earthquake and to the 2010 Haiti earthquakes could not have been the same, for example. Whereas the Chinese government controlled the overall relief effort, the Haitian president "has waited for nine days before officially speaking to the country. Like Godot, we were waiting for him and we are still waiting" [Val10]. At least these two humanitarian deployments took place in a relatively safe region. But disasters do not always occur in the most stable political environments. Remember the 2002 volcanic eruption in Rwanda: "the Nyiragongo eruption took place within the context of a civil war that has cost at least 2.5 million lives since 1998. Some UN agencies and NGOs reported that they were concerned that having the official government endorse particular steps, especially those related to resettlement, might lead the population to reject them out of hand" [LK07]. Collaboration networks involving humanitarian organisations can therefore take many forms, depending on the stakeholders involved, their objectives, and the level, local or global, at which they are implemented. We have drawn up a panorama of various existing collaboration modes and their applicability, stressing the diverse barriers and enablers to implementation. The choice of the most appropriate collaboration mode is never easy, but this is especially true in a context of humanitarian crisis. Figure 2.8 on the following page proposes a clear decision tree for facilitating this crucial decision, based on practitioner interviews and literature review.

This section details various collaboration modes and their applicability to the context of disaster management. It illustrates the particularities of the humanitarian sector and the specific problems they create. Our approach is a first step aimed at a better understanding of those particularities. It sets the basis for successful applications of research on collaboration networks in this sector. Yet though we built the models with a great deal of input from practitioners, there is additional work needed, especially to validate the decision process proposed in figure 2.8 on the next page.

2.9.5 Vertical coordination

Mobilisation and affectation: balancing

Some humanitarian organisations evolve in several fields at the same time. Thus there are several projects to manage in parallel. Such organisations have to globally control all these

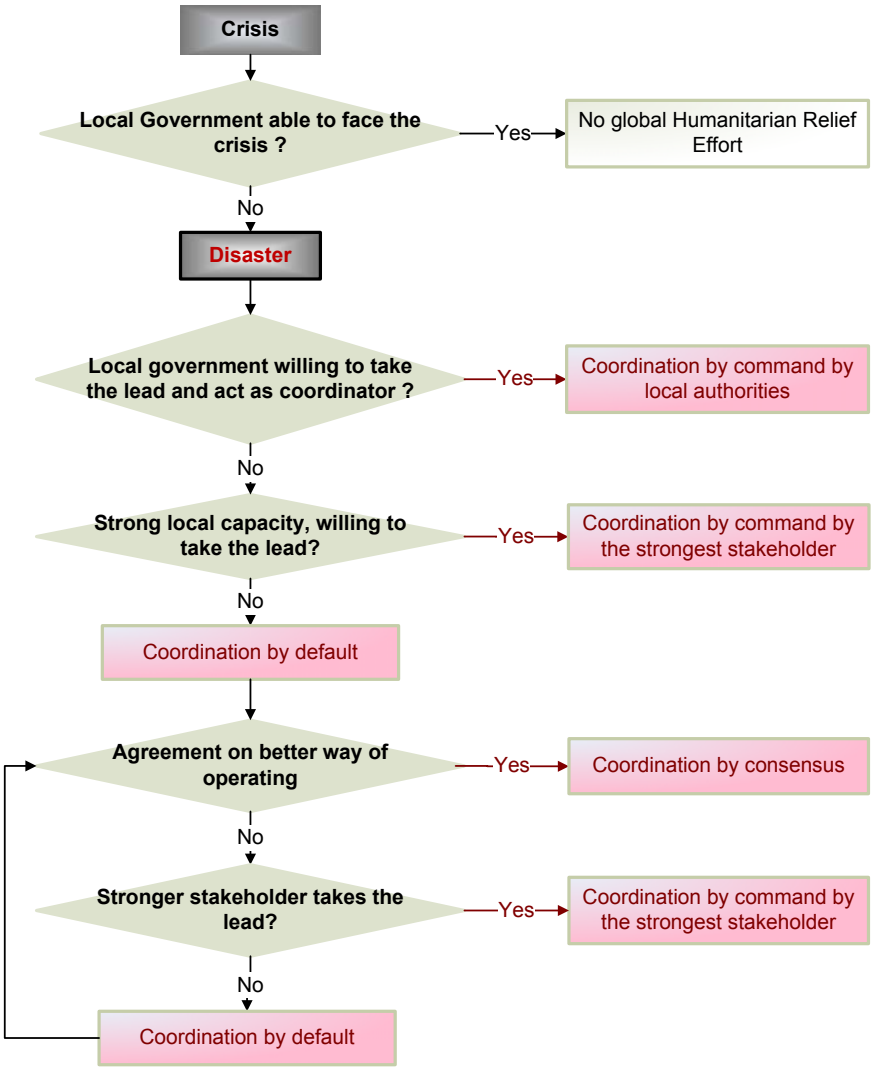


Figure 2.8: Decision tree created to facilitate the choice of the most adequate coordination mode

operations. Because they are under-resourced they have to define priorities in order to properly dispatch funds and, of course, personnel. This is not always easy. According to [TK05], "in order to effectively respond to the Tsunami, 88% of large aid agencies surveyed had to pull their most qualified staff from the ongoing humanitarian operations in Darfur". Globally, this is a problem of balancing (Figure 2.9 on the facing page).

Coherence and efficiency: synchronisation

Moreover, the same humanitarian organisation can fulfill various SHUs[13] in the HSC. A typical example is the International Federation of Red Cross (IFRC) that have headquarters in Geneva, three Relief Logistics Units (in Panama, Dubai and Kuala Lumpur) and more than 180 National Societies all over the world. Consequently, when a crisis occurs, several members of the

[13] strategic humanitarian unit

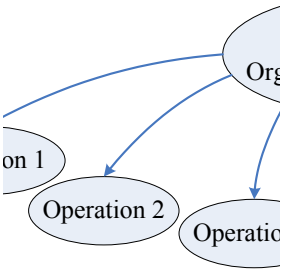


Figure 2.9: Balancing component of vertical coordination

Federation operate in a same place. Headquarters has to guarantee the coherence and the efficiency of the global action of the network on this crisis. Consequently, the SHU must synchronise its actions in order to be increasingly effective and reactive. Globally, this is a problem of synchronisation.

Empowerment and best practices: training

The two precedent components of vertical coordination relate to phases 1, 2 and 3 of the life cycle (see figure 2.1 on page 22). But phase 0 could also be included in the vertical coordination. Indeed, during the preparedness phase, a humanitarian organisation should capitalise on its past experiences in order to define best practices in terms of supplier selection, business processes, skill management, etc. According to many humanitarian workers, “the success or failure of humanitarian response and coordination is too often dependent on ‘personalities’”. The independent 2007 Cluster Approach Evaluation Report [UNO07] noted that "attributing everything to personality underplays the degree to which institutions can and do shape the behaviour, practices, and skills of individuals". But experts note that the potential of this institutional shaping is hampered by the fact that "the humanitarian community has many serious weaknesses in managing human resources, from recruitment to training to appraisal" [VAI08]. The aim of this coordination could be to ensure the use of these best practices during future operations. Moreover, personnel probably have to learn from each other in order to be more efficient in the future. Of course, the objective is not standardisation because each crisis is unique. Globally, this is a problem of training and knowledge management.

Vertical coordination components

To summarise, vertical coordination seems to include three major components (Figure 2.10 on the following page):

1. Balancing: To mobilise and properly allocate the funds and skills to different crises at a given time.
2. Synchronisation: To guarantee the coherence and efficiency on a relief operation.
3. Training: To facilitate the empowerment between network members and the implementation of best practices.

According to the framework presented in figure 2.10 on the next page, the vertical coordination seems to require relevant operational reports, formalised strategies, business processes and procedures, and probably also an efficient Information System.

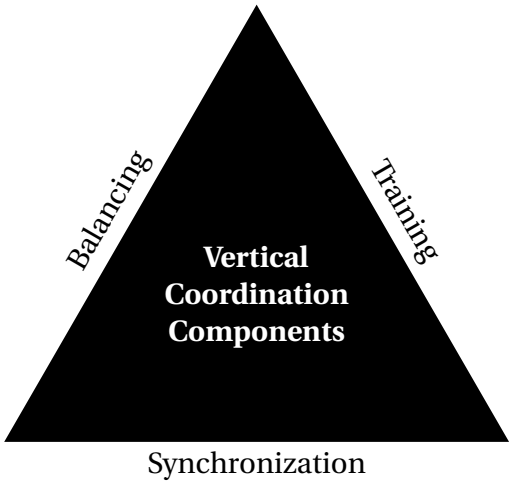


Figure 2.10: Vertical Coordination Framework

3

Literature review and research statements

3.1 A new, attractive area of research

The number of scientific articles dedicated to the study of the humanitarian supply chain, either general or focussed on a specific issue, was remarkably low five years ago. This has changed recently with the publication of a substantial number of papers related to disaster management. Table 3.1 provides an overview of the quantity of publications on humanitarian supply chains over the past few years. This is only a partial view of the existing literature, as many articles have been published in journals related to refugees, developmental studies, health issues and many other specific journals which do not always appear in academic databases. Neither do NGO reports, which also provide many useful analyses and discussions on the subject. Finally, military academics provide abundant literature on this issue too, but little is publicly available.

If we focus on standard available academic databases, the number of articles is becoming significant. Figure 3.1 on the next page illustrates the growth of academic literature over the last twelve years. A dedicated journal, the Journal of Humanitarian Logistics and Supply Chain Management is even forthcoming in 2011. Due to the youth and attractiveness of this new

Table 3.1: A quick scan of the existing literature on humanitarian supply chains/logistics

Key words	Database			
	Science Direct search within all content	Science Direct search within title, abstract and key words	ISI Web search within topic	Springerlink search within all content
Humanitarian Supply Chain	665	9	15	447
Humanitarian Logistics	625	17	34	440
Humanitarian Supply Chain and Logistics	147	7	10	115
Total articles Humanitarian Supply Chain and/or Logistics	1143	19	39	772

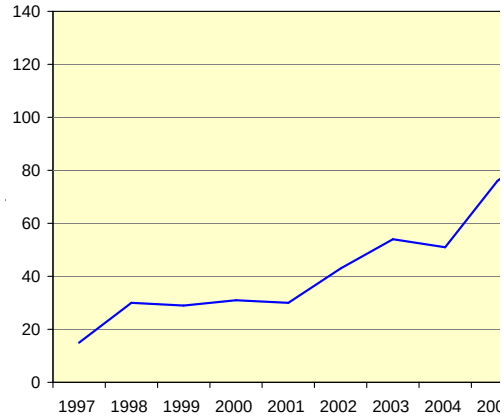


Figure 3.1: Number of publications per year on humanitarian supply chains / humanitarian logistics, in Science Direct

area of research, it is difficult to have an exhaustive, up-to-date literature review of the subject. This chapter will nevertheless provide the reader with an overview of the existing literature on humanitarian supply chains. The analysis will focus first on research types and contributions, then on their specific scopes of study.

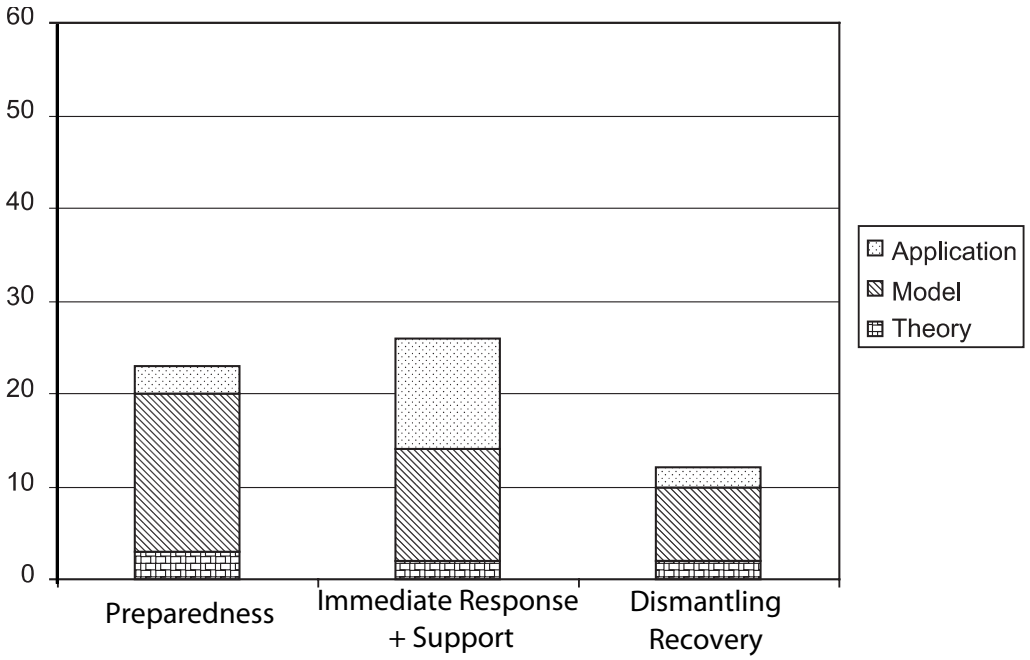
3.2 Overview of research types, contributions and methodologies

According to [DUT03], three types of research are used in OR/MS: Management sciences, management consulting and management engineering. In management sciences, "the goal is to develop new results to contribute to the body of knowledge in the discipline". As for management consulting, "the goal is to solve somebody's practical problems using existing, standard methods". Management engineering is between the two, as its goal is "to solve those practical problems for which it is necessary to adapt existing tools in fundamentally novel ways."

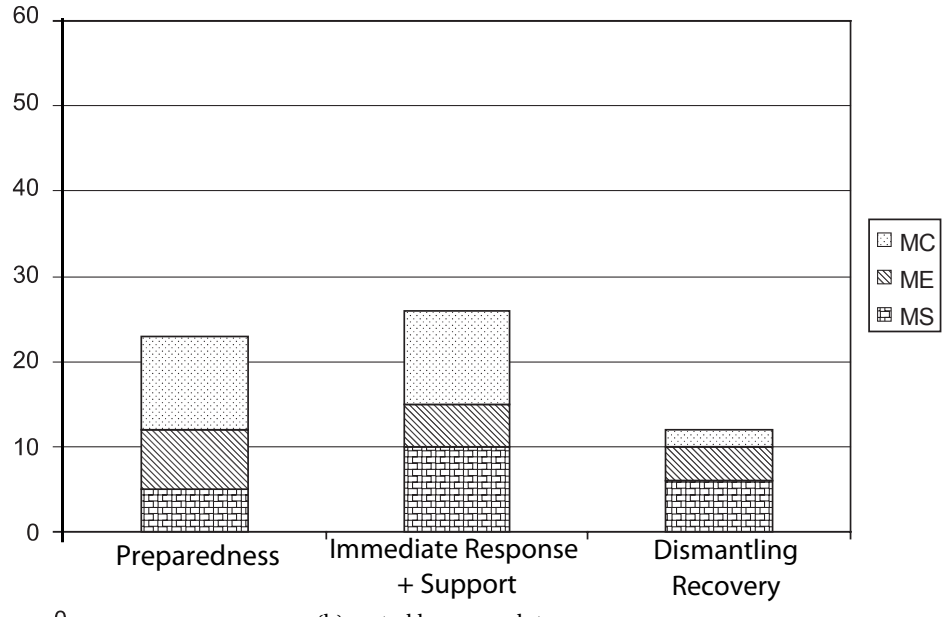
According to [AG05], management engineering is by far the most widely used, followed by management consulting (see figure 3.2). This may be due to the relative youth of this area of research. If we now sort the articles by disaster contributions, more than half of the research published is on model development (analytical models for solving and analysing problems or for estimating outcomes), followed by theory (26.6% of the research tests hypotheses, investigates the behaviour of systems, or provides a framework and advances our understanding of some phenomena in the field) and application development (15.6%), when a computer tool is produced or a prototype is developed (see figure 3.2 from [AG05]).

As for research methodologies, according to [AG05] "mathematical programming, including heuristics, is the most frequently utilized method, followed by probability theory and statistics, although the use of the latter is much less frequent. Simulation appears third in the list. Decision theory and multi-attribute utility theory (MAUT - see section 14.2.2 for more details) are also used in DOM[1] research." As for other methods, such as systems dynamics, constraint

[1] Disaster Operations Management



(a) sorted by research contribution



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(b) sorted by research types

MC=Management Consulting: "the goal is to solve somebody's practical problems using existing, standard methods"
ME = Management Engineering: "the goal is to solve those practical problems for which it is necessary to adapt existing tools in fundamentally novel ways"
MS = Management Science: "the goal is to develop new results to contribute to the body of knowledge in the discipline" [DUT03]

Figure 3.2: Distribution of research contributions and research types to life cycle stages of Disaster and Operations Management, from [AG05]

programming and soft OR techniques, they are extremely rare. [AG05]. Research is underway to fill this gap. Among others, [Gon08]; [MW09] as well as an article from Besiou, expected at the end of 2010, are using systems dynamics. Soft OR techniques have also been used recently, especially Business Process Reengineering [Cha+08]; [CLT09].

3.3 Reviews sorted by scope of study

Two articles have surveyed the existing literature: [KS07] and [AG05]. The first focusses on papers concerning supply chain issues, whereas the second includes any topic, as long as articles are related to disaster management and use operations management or operations research approaches. These literature reviews have different scopes but similar findings. According to [KS07], "academic literature on humanitarian logistics tends to concentrate on the preparation phase of disaster relief." If we refer to [AG05], what Kovacs and Spens call preparation should be divided into mitigation efforts and preparedness efforts. With this distinction, the work done to mitigate the effects of potential disaster comes first in the list of areas studied.

This is aligned with the fact that while funds are abundant for immediate response, the funding of disaster preparedness, though vital, is often neglected by donors (see section 2.5 on page 24). Having neither significant funds for working on preparedness nor any pressure from donors to do so, NGOs dedicate most of their efforts on immediate relief operations, finding and implementing more effective ways to provide assistance in the first weeks following disasters. As a result, a tremendous opportunity exists for academics to help in providing efficient solutions in disaster preparedness and mitigation.

3.3.1 Disaster preparedness

"A successful humanitarian operation mitigates the urgent needs of a population with a sustainable reduction of their vulnerability in the shortest amount of time and with the least amount of resources" [JH08]. Consequently, a successful response to a disaster is not improvised and must be prepared to be effective. Humanitarians have begun to heed the lessons learnt from previous disasters and realise that they have to work hard not only during disasters but also between disasters [UNO05b]. According to Van Wassenhove [Was06b], preparedness consists of five key elements that have to be in place to produce effective results. These in turn lead to effective disaster management. They are as follows

1. Knowledge management

   Learning from previous disasters by capturing, codifying and transferring knowledge of logistics operations. See [Int06]; [Kai+03]; [Ben+03] and [JH08]. [Bea99]; [KS05] and [MEW09], among others)

2. Financial resources

   Preparing sufficient financial resources to prepare and initiate operations and ensure that they run as smoothly as possible. See [JH08]; [Sta+09] and [Ble09] for details.

3. Human resources

   Selecting and training people who are capable of planning, coordinating, acting and intervening where necessary. The problem of human resources in humanitarian operations is probably the most forsaken one in terms of academic research. Nevertheless,

many authors, such as ([Nat91]; [TW05a]; [Int06]; [WS03]; [Was06a]) have demonstrated how crucial this problem is. The shortage of qualified staff and the high level of turnover often have harmful consequences on the management of crises. However, methods exist in business management that should be adapted to design relevant skills management systems for the humanitarian sector.

4. The community

   Finding effective ways of collaborating with other key players such as governments, the military, businesses and other humanitarian organisations is not an easy task. See [Ben99]; [TW05a] for an application of "organisational design" best practices for humanitarian relief. [PB05] have detailed the relationships between military and humanitarian organisations. See also [Ken04]; [Mul02] and [WS03] for details of centralised coordination around a UN Agency. More recently, [Bal+10]; [CLT10] and [CP10] looked at collaboration in the context of relief chains and summarised its barriers and enablers.

5. Operations and process management

   Recognising logistics as a central role in preparedness. Then setting up goods, agreements and the means needed to move resources quickly. Several papers treat operations and process management in HSC. They study mainly the improvement of unitary operations or business processes in a humanitarian context. Examples include transportation and inventory management ([SMW09]; [Why07] and [AB06], among others); the development of flexible technology and software for supporting humanitarian operations [BH08]; and metrics and performance measurement in a humanitarian context ([Dav06] and [BB08], among others).

3.3.2 Disaster response

If we refer to [KS07], "the main problem areas of the immediate response phase lie in coordinating supply, the unpredictability of demand, and the last-mile problem of transporting necessary items to disaster victims." 40% of the articles focussing on disaster response try to keep their work applicable for any disaster type (see [SP81]; [SR05] and [BV93] among many other). 60% studied specific disasters, like earthquakes ([BA04]; [FGR00]; [OEK04]), floods [Olo10], industrial accidents ([KKM01]; [PF00]; [Gel+09]; [VP04]; [SW97]) or terrorism ([BKW10]; [Cyg03]; [Bra00])

3.3.3 Disaster recovery

Research in organisational behaviour and decision science or any area outside OR/MS is abundant. As for OR/MS-related articles, there are not many; only 11 articles in 15 years. The proportion of contributions on recovery in general, compared to those focussing on specific disasters, is roughly the same as the division on disaster response. 45% of papers concentrated on recovery in general whereas the remaining 55% focussed on a specific disaster, be it natural or man-made (see [AG05] for details).

3.4 Publications of NGOs

Those academic publications are not the only references we can find on humanitarian supply chains. Many organisations also publish internal or public reports to share their findings and

questions. A large proportion of these reports analyse their past operations, outlining not only their achievements, but also the issues they faced. Most of these reports are available on centralised websites, such as ReliefWeb[2], Fritz Institute[3], ICVA[4] and GHA[5], or directly on UN cluster or organisations' websites. If we consider reports providing an analysis of relief operations responding to the 2004 tsunami, ReliefWeb centralises 138 reports in total, 35% posted by academics, 40% by NGOs, 20% by INGOs or UN agencies and the rest by governments. Most of them provide many useful accounts and quantified analyses given by practitioners.

Another subject often dealt with in NGO reports is the past, present and future of humanitarian demand ([Pro04]; [IFR07b]). Some provide overviews on "forgotten" emergencies to increase awareness of donors and media on all the underfunded disasters [IFR07b]. See chapter 11 on page 103 for an analysis on this specific issue.

3.5 Analysis and conclusion

An increasing number of articles have been published on humanitarian operations, be they focussed on one phase of the response or more generally. Some have used mathematical models, others softer methodologies like case studies. A few articles, and more recently a book, take a general point of view and provide basic knowledge on humanitarian operations and their specificities. These usually seek to draw the subject to the community's attention. They provide an overview of humanitarian supply chains, their issues and challenges, and propose ways forward. See [Bea04]; [Was06b]; [TW09]; [TK05]; [KS07], among others. Most of them agree on the fact that "future research in humanitarian logistics would include improved methods for inventory control, distribution system design, cooperation and coordination, and performance measurement, under the unique characteristics of the humanitarian relief supply environment." [Bea04] They usually emphasise opportunities for improving the management of humanitarian supply chains, but few of them acknowledge the fact that the opportunity for improvement also concerns the private sector. The capability of humanitarians to respond quickly and adequately to changes, though vital for humanitarian organisations, is scarely analysed nor understood [OG06]. Yet this is an area where both humanitarian and commercial supply chains would greatly benefit from a clear assessment tool that would help them define their improvement path.

As discussed in the literature review, humanitarian supply chains are a new area of study. There are therefore many issues that deserve to be studied. Table 3.2 on the facing page summarises the main leads for research highlighted by the literature review and summarises the elements which explain our choice of research objectives.

On the basis of the analysis presented in table 3.2 on the next page, we chose to focus on the most obvious cross-learning opportunities between humanitarian and commercial supply chains, that is to say their ability to respond quickly to changes. The work on this ability, called agility, will be presented in the second part of the thesis. As supply chain agility depends on the design of the logistics network, the last part of this thesis focusses on the configuration and design of supply networks compliant with humanitarian specificities. The choice of this research objective is motivated by its importance for humanitarians as well as for its added academic value as it appears to be a gap in the current literature.

[2] http://www.reliefweb.int
[3] http://www.fritzinstitute.org/
[4] The International Council of Voluntary Agencies (ICVA), http://www.icva.ch/
[5] Global Humanitarian Assistance, www.globalhumanitarianassistance.org

Table 3.2: Our choice of research objectives

Leads	In our scope?	Reason
General understanding of HSCs, their specificities and needs	ok	New area of research, with many constraints to take into account. Many articles use a management consulting approach and use existing tools and techniques without adapting them. This may impact the validity of their results as they do not always have a clear vision of field realities.
Knowledge management	ko	Significant international projects have been launched on this issue, with dedicated resources. Some articles also published; no need for us to add another layer to these reflections.
Financial resources	ko	Not an area where academics can help a lot, as the major barriers are organisations and donors' incentives.
Human resource issues	ko	As it is, coordination and communication rely too heavily on personalities. The right people are definitely needed at the right place, so it is worth working on the idea of building a tool to ensure HR pools in line with needs in term of skills and quantity. However, this isn't really an issue related to "industrial systems", and therefore lacks relevance for this specific thesis.
The community	ok	Difficulties collaborating with other humanitarian stakeholders are outlined as one of the major weaknesses of humanitarian organisations (see chapter 3 on page 37). This point is analysed in section 2.8 on page 27
Operations and process management	ko	Covers a wide range of possibilities, from transportation and inventory management to the development of flexible technologies and software for supporting operations, and tracking and measuring performance. Many of these applications are already under study.
Design and configuration of a supply network	ok	Cross-learning validated: this would improve humanitarians' efficiency while guaranteeing their speed and effectiveness. The agility of the private sector could also be improved.
Managing a supply network	ko	Working on inventory management and decision would optimise humanitarians' efficiency and could benefit the private sector should they face a high level of uncertainty. This issue requires a dedicated thesis. Karca D. Aral, PhD student from INSEAD is currently working on this problem.
Needs assessment	ko	This research proposal has no value added for humanitarians in the current situation. Indeed, at a single organisation level, they already have formalised tools and methods (see [IFR05b]; [IFR01]; [IFR05a], and [UNO00] among others) What is needed is a common consolidated needs assessment, but this is more a political issue. Assessments are influenced by how an organisation works and its vision on the range of activities considered "humanitarian". As a result, it is not interesting to develop an overall assessment tool before they align and share their views on the subject.
Best practices in terms of agility	ok	Cross-learning potential validated by literature review and interviews

3.6 Our problem statements: agility and supply-chain design

This thesis aims to improve the management of both humanitarian and commercial supply chains by using cross-learning. The idea is thus to find and develop areas where humanitarians could benefit from their counterparts' expertise, and vice versa.

If we summarise the main strengths of commercial and humanitarian supply chains, the cross-learning potentiality becomes obvious. Whereas humanitarian supply chains need flexibility, effectiveness and responsiveness to enter the arena, commercial supply chains mainly need efficiency. And if we talk about market winners, the criteria are exactly the opposite: humanitarians are focussing more and more on efficiency to make the difference, whereas flexibility, effectiveness and responsiveness are becoming highly prized by the private sector. (see table 3.3)

Table 3.3: Cross-learning opportunities Inspired by [CT00].

	Market Qualifier	Market Winner
Market-Driven Commercial Supply Chains	Lead Time Cost	Availability
Customer-Driven Commercial Supply Chains	Cost Availability	Lead Time
Humanitarian Supply Chains	Availability Lead Time	Cost

The second part of our thesis will therefore focus on supply chain agility. Its analysis of the various elements, which enable a supply chain to be agile, justifies the choice of our third research objective. Indeed, agility depends on the adequacy between capacity and needs It also depends on the local capacity that you can build by establishing and running a local warehouse. Yet those elements have a cost. It is therefore of prime importance to ensure an adequate level of service at lesser costs. This is not an easy task, especially when you operate in highly uncertain conditions and when the stakes of the success are human lives, which should be priceless. Some work has already been done on supply network design for the private sector. Our input here will be to quantify the impact on costs of various factors such as the quickness and amount of the relief aid or the size and location of warehouses. The aim is to facilitate the choice of the optimal logistics network to implement. (see figure 3.3). This analysis is developed in the third part of this thesis.

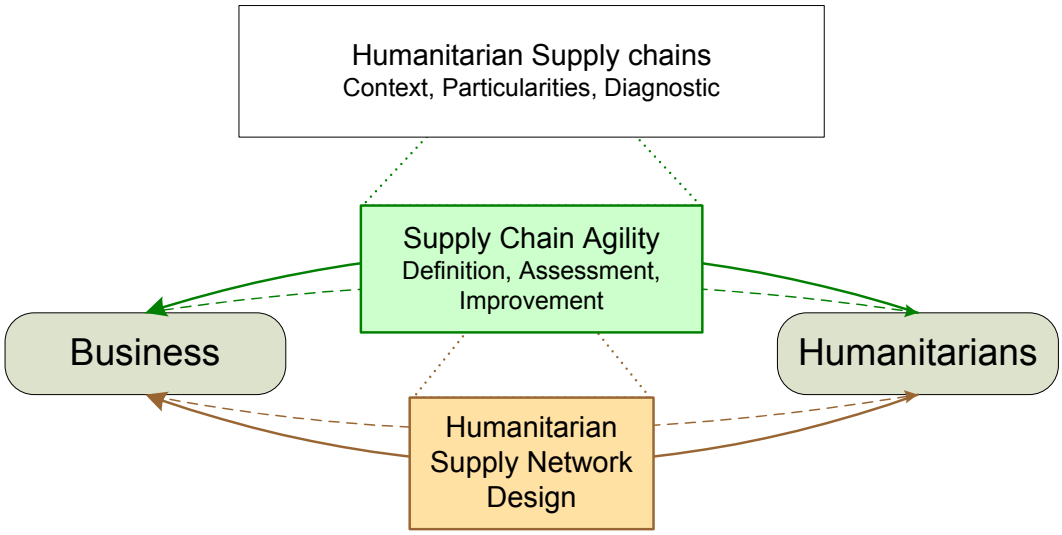


Figure 3.3: Research Objectives

PART II

Supply Chain Agility

Definition, Assessment and Improvement

Purpose: By constantly working in environments with high degree of uncertainty, humanitarian organizations end up becoming specialists in the implementation of agile systems. Their counterparts in profit-making organizations have a lot to learn from them in this domain. Volatility of demand, imbalance between supply and demand, and disruptions are all factors that affect commercial supply chains and call for a high level of agility. The aims of this part are twofold: firstly to clearly define the concept of supply chain agility, and secondly to build a model for assessing the level of agility of a supply chain.

Design/methodology/approach: Three approaches are used in this research: literature review, case study and symbolic modeling.

Findings: We developed firstly a framework for defining supply chain agility and secondly a model for assessing and improving the capabilities of humanitarian and commercial supply chains in terms of agility, based on an analysis of humanitarian approaches.

Research limitations: Our model has been developed thanks to inputs from humanitarian practitioners and feedbacks from academics. The practical application to various humanitarian relief operations and commercial supply chains is yet to be done.

Originality/value: This thesis contributes significantly to clarifying the notion of supply chain agility. It also provides a consistent, robust and reproducible method of assessing supply chain agility, which seems appropriate for both humanitarian and business sectors. Finally, it is complementary to existent research on humanitarian logistics. It shows that though humanitarian professionals have a lot to learn from the private sector, the reverse is also true.

Introduction and Research Questions

One of the particularities of humanitarian logistics is the level of uncertainty they have to cope with. Every day, in many parts of the world, humanitarian workers are confronted with various forms of uncertainty. Given that beneficiaries' needs evolve over time and are really difficult to forecast, demand and supply vary on a daily basis. Also, there are many cause-and-effect interactions that affect operations. For example, an earthquake can provoke a flood if a brimming lake is formed by landslides from the earthquake. Local infrastructure may also be damaged to the extent that the supply chain network has to be continuously rethought, along with the reconstruction of roads, airports and other key elements of the network. Humanitarian logisticians have therefore developed tools and methods to respond quickly to short term changes, thereby improving the agility of their supply chain.

This high level of agility is more and more required in the private sector. Indeed, "in addition to the risks of mismatch in supply and demand, disruption is an increasing risk in global supply chains even for the private sector. With longer paths and shorter clock speeds, there are more opportunities for disruption and a smaller margin for error if a disruption takes place" [KW04]. Many examples can be used to illustrate the low responsiveness of most commercial supply chains. After the earthquake in Taiwan in 1999, the prices of Global semiconductor were almost doubled, and of the 62 companies based in Asia, only 21% had full business contingency plans to protect themselves against business interruption [For08]. Demand volatility is also becoming higher in the private sector. Due to market turbulence, demand in almost every industrial sector seems to be more volatile than it used to be in the past [CL04]. Consequently, being able to react quickly to changes is an essential capability for commercial supply chains, especially in our globalized world where "fierce competition is not based any more on price alone but also on the "freshness" of the offer: constantly changing assortment, newest fashion and best opportunity" [KS09].

Cross-learning opportunities between business and humanitarian sectors have been listed by many authors ([Was06b]; [OG06]). Today, disaster relief is becoming a testing ground for many researchers in logistics. More often, they propose methods for implementing in the humanitarian sector the tools that they initially designed for the business sector. Yet, to date, no work seems to have been done the other way round. In other words, no one has explicitly identified the best practices that the business sector can borrow and adapt from humanitarian experts. This thesis aims to fill this gap in line with our belief that the business and humanitarian sectors can both learn from each other.

From an academic point of view, supply chain agility is becoming a major field of research. It is highlighted as one of the fundamental characteristics of the best supply chains [Lee04]. Given the complexity that is linked to a high level of constraints and uncertainty, the humanitarian sector is an interesting field to study. Moreover, they present a potential added value for both

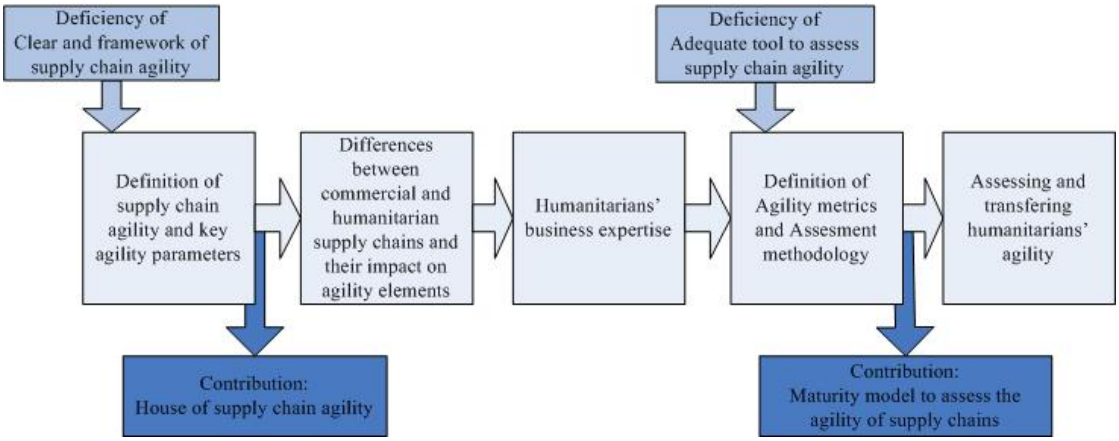


Figure 3.4: Our approach step by step

the humanitarian and the private sectors. It is very important for humanitarian organizations to explicitly establish the best practices found in relief chains, and by so doing, they clarify their achievements and facilitate the ramification of these best practices. The business sector could then learn from them in order to improve the agility level of their supply chain. It would enable them to deal with supply, demand and environment uncertainties, and this capability is becoming an order-winner for many commercial supply chains.

Many supply chain managers are therefore in search of methods that would enable them to better assess the level of agility of their supply chain. Unfortunately, in the literature, there is no unanimously accepted framework and consistent system for defining and measuring supply chain agility. We can therefore formulate two research questions (RS) as follows:

- RS1: How should supply chain agility be defined?
- RS2: How should supply chain agility be assessed?

Based on the review of literature, we will, in chapter 4 on the facing page, address the first research question and present our framework in the form of a house that we will refer to as the "House of supply chain agility". The second research question will be studied in chapter 5 on page 57. By analysing the capabilities of the major existing approaches, this study evaluates the different ways of assessing supply chain agility. A comparative analysis of the main features of both the humanitarian and the commercial supply chains is done in order to ensure that our assessment is valid for both sectors. Chapter 6 on page 63 makes explicit humanitarians' business expertise. This study details various methods developed by humanitarian organisations in order to ensure the agility of their supply chain. Similar methods recommended by researchers are also listed. The model in itself, together with its application in the humanitarian sector to illustrate the logic of our approach are presented in chapter 7 on page 67. this last chapter will present our analysis, conclusions, limitations and perspectives for further research. Figure 3.4 shows a step-by-step view of our approach.

4

How should supply chain agility be defined?

In the last decade, agility has been one of the key concepts discussed by many authors. We have therefore reviewed the literature in order to gather its various definitions and dimensions as it applies to supply chains. In this chapter, we do not intend to provide an exhaustive literature review but simply a quick scan that is elaborate enough to enable clarify the notion of supply chain agility and to build a consistent assessment model. Only the conclusions of our literature review are therefore presented.

4.1 Agility, Resilience, Adaptability : what are the differences ?

Supply chain agility is usually defined as the ability to respond to unanticipated changes [She04]. As we have seen in section 2.7 on page 26, there are four sources of uncertainty: foreseeable uncertainties, residual risks ("what is left over after planning for foreseeable uncertainty"), complexities and unknown unknowns ("those that do not have a definite formulation, have no stopping rule that allows one to determine when the problem is solved, where solutions cannot be fully tested and the problem cannot be generalized, and where there is ambiguity on the causes of the problem") [LDP06]. Agility would then mean to be able to respond quickly when confronted with any of these uncertainties.

The focus on agility from the supply chain perspective emerged in the year 2001 and was first initiated by [HHC01]. According to [Lee04], the main objectives of an agile supply chain are responding quickly to short-term changes in demand (or supply) and handling external disruptions smoothly. Sometimes agility could be mistaken for other similar but different concepts such as adaptability and resilience.

While agility is being able to deal with and take advantage of uncertainty and volatility, adaptability is rather used for more profound medium-term changes. Adaptable supply chains adjust their design to meet structural shifts in markets and, modify and adapt the supply network to strategies, products, and technologies [Lee04]. Figure 4.1 on the following page shows an illustrated difference between agility and adaptability.

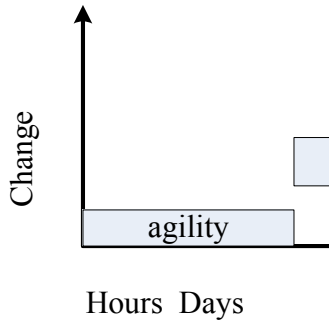


Figure 4.1: Agility vs. Adaptability, in [McC+06]

Table 4.1: Agility vs. Resilience

Supply Chain Ability	Structural properties	Deals with	Aims at
Agility	Flexibility	Volatility, Uncertainty	Quick satisfaction of customer
Resilience	Robustness	Identifiable risk of disruption	Business Continuity

As for resilience, it aims to mitigate identifiable risks and ensure continuity in the firm's business. [CP04] defined resilience as the ability of a system to return to its original state or move to a new and more desirable state after being disturbed. Differences between agility and resilience are depicted in Table 4.1.

4.2 Agility versus leagility

Shortly after the emergence of agility, the concept of leagility appeared. According to Agarwal, leagile is the combination of the lean and agile paradigms within a total supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand down stream yet providing level scheduling upstream from the market place [HHC01]. The decoupling point is in the material flow streams to which the customer orders penetrates ([AST06], inspired from [MNT00] [PK03]).

The applicability and relevance of this concept of leagility in the context of humanitarian aid may be questioned. Table 4.2 on the facing page summarizes the distinguishing attributes of lean, agile and leagile supply chains. Chapter 2 underlined the major specificity of humanitarian supply chains : the vital importance of the success of operations. Lead time and availability are therefore of prime importance for beneficiaries, which justifies the focus on supply chain agility, at least in this first approach. The migration from agility to leagility will be taken into consideration later, in the third part of this thesis. Indeed, we agree with Van Hoek that "leagility might work well in operational terms as lean capabilities can contribute to agile performance and might often be a prerequisite. If the leagility approach is to work, though, it is required to fit within a purely agile supply chain strategy, rather than a purely lean approach." [Hoe00]

Table 4.2: Comparison of lean, agile, and leagile supply chains, from [AST06] and inspired by [NNB99] ; [MNT00]; [Olh03] ; [BDT04]

Distinguishing attributes	Lean supply chain	Agile supply chain	Leagile supply chain
Market demand	Predictable	Volatile	Volatile and unpredictable
Product variety	Low	High	Medium
Product life cycle	Long	Short	Short
Customer drivers	Cost	Lead-time and availability	Service level
Profit margin	Low	High	Moderate
Dominant costs	Physical costs	Marketability costs	Both
Stock out penalties	Long term contractual	Immediate and volatile	No place for stock out
Purchasing policy	Buy goods	Assign capacity	Vendor managed inventory
Information enrichment	Highly desirable	Obligatory	Essential
Forecast mechanism	Algorithmic	Consultative	Both/either
Typical products	Commodities	Fashion goods	Product as per customer demand
Lead time compression	Essential	Essential	Desirable
Eliminate muda	Essential	Desirable	Arbitrary
Rapid reconfiguration	Desirable	Essential	Essential
Robustness	Arbitrary	Essential	Desirable
Quality	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market qualifier	Market winner
Lead-time	Market qualifier	Market qualifier	Market qualifier
Service level	Market qualifier	Market winner	Market winner

4.3 Definition of supply chain agility and its performance dimensions

4.3.1 Literature review, definition and historical perspective

To achieve a high level of agility, a supply chain has to acquire some key capabilities. Many authors have already listed one or more elements associated with agility. Table 4.3 shows the definitions and details of these capabilities. The aim of this section is to illustrate all the facets of agility that have to be worked on. The House of Supply Chain Agility (see figure 4.2) summarizes the main components, which enable the supply chain to be agile. We developed it based on a thorough literature review on agility.

4.3.2 Key characteristics of agile supply chains

According to [CT00], a key characteristic of an agile organization is flexibility. In other words, supply chain agility is an externally focused capability that is derived from flexibilities in the supply chain processes [SGM06]. They thus assert that “procurement/sourcing flexibility”, “manufacturing flexibility” and “distribution/logistics flexibility” positively impact supply chain agility”. Manufacturing flexibility is broken down into four competences (machine, labor, material handling and routing flexibilities) and two capabilities (volume flexibility and mix flexibility) [ZVL03]. Knowing that internal manufacturing flexibility competencies are

neither relevant to our focus on supply chains nor appropriate for service providers such as humanitarians, we will restrict our study to capabilities as pertained to flexibility. We will therefore adopt and study four flexibility capabilities (product flexibility, mix flexibility, volume flexibility and delivery flexibility) as they are defined and classified by [Sla05], and summarized in Table 4.3. There is abundant literature on the notion of agile manufacturing ([YSG99]; [SZ99]; [Gia+03]).

Consequently, flexibility is a requirement that is necessary to achieve supply chain agility. It is therefore represented as the foundation of the House of Agility. Though a key component, it is not the only capability needed to achieve supply chain agility. Enhanced responsiveness is also a major capability of an agile supply chain [SS07]. Two other key ingredients of agility are visibility and velocity [CLP04]; [CP04]. A complementary capability is mentioned by [Oko+08], for whom agility in a supply chain is the combination of effectiveness and responsiveness in a flexible environment.

As shown in Table 4.3 on the next page, our framework will be organized in the following order and manner: flexibility is broken down into four capabilities (volume, delivery, mix and product flexibilities); responsiveness into three capabilities (reactivity, velocity and visibility); and effectiveness is composed of completeness and reliability. All these enable to provide a quick and adequate response to short-term changes. The definitions of these capabilities are given in Table 4.3. It also provides an overall assessment of humanitarian and commercial supply chains, thus moderating our approach. Indeed, even if humanitarian are a step ahead for most agility capabilities, some of them are more developed in the private sector. A comparative analysis of each sector is thus essential to better define the scope of the study and comprehend the value of our approach. Table 2.1 on page 29, presented in section 2.7 provides some inputs on the matter.

Based on this discussion, we can define supply chain agility as the ability to respond quickly and adequately to short-term changes in demand, supply or the environment. It is derived from the flexibility, responsiveness and effectiveness of the supply chain.

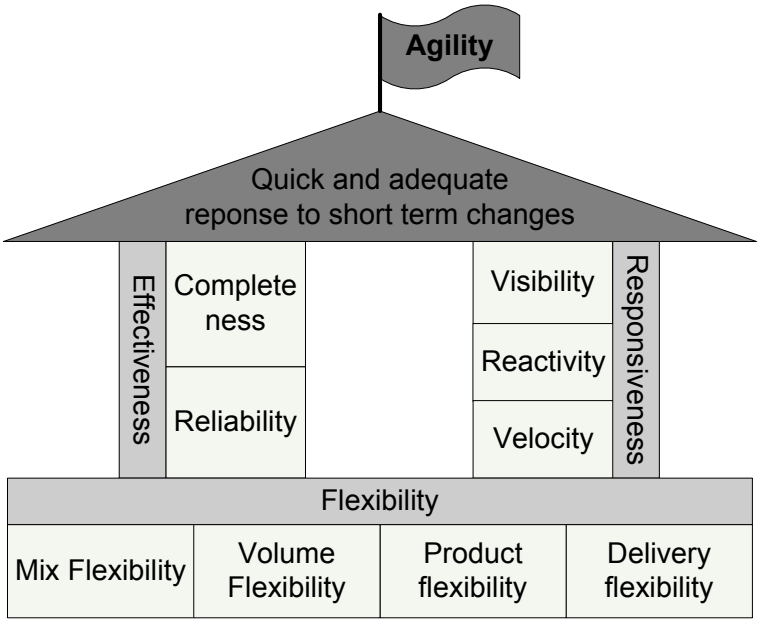


Figure 4.2: House of Supply Chain Agility

Table 4.3: Supply Chain Agility Capabilities : Definitions and Assessments
(CSC = Assessment for Commercial Supply Chains, HSC = Assessment for Humanitarian Supply Chains)

	Capabilities	Definitions	CSC	HSC
Flexibility Ability to change or react with little penalty in time, effort, cost or performance [TT05]	Volume Flexibility	Ability to change the level of aggregated output. [Sla05]	++	+++
	Delivery Flexibility	Ability to change planned or assumed delivery dates [Sla05]	+	+++
	Mix Flexibility	Ability to change the range of products made or delivered within a given time period [Sla05]	++	+++
	Product Flexibility	Ability to introduce novel products, or to modify existing ones [Sla05]	++	+
Responsiveness Ability to respond to change within an appropriate time frame [GP00]	Reactivity	Ability to evaluate and take needs into account quickly	+	+++
	Velocity	Ability to cover needs quickly	+	+++
	Visibility	Ability to know the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events [Ver08].	++	+
Effectiveness Doing all the right things	Reliability (doing the right thing)	Ability to deliver the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct user [Cou06]	+++	++
	Completeness (doing all)	Ability to realize the goals	++	++

5

How should supply chain agility be assessed?

5.1 Why assessing agility?

If we presume that agility is the future business system that will replace the mass production businesses of today [Kid95], then it will be of prime importance to have a logical, consistent, robust and reproducible model that will be used to assess supply chain agility. This is true for the business, as well as for the humanitarian sector where a high level of agility is needed. The use of a model to assess supply chain agility should:

- Emphasize the vital need of humanitarians for preparedness, and this would constitute an additional argument to motivate their donors to increase funds for disaster preparedness actions.
- Provide supply chain managers with effective ways of collaborating with other stakeholders in order not only to enhance benchmarking and cross-organizational learning, but also to mutually improve the agility capabilities of their supply chains.
- Enable to measure performance, better manage skills and abilities, and facilitate knowledge management, which constitutes a path toward self-improvement.

In this chapter, we will start by studying existing methods of assessing agility capabilities. Then, we will explain the reasons why we propose a benchmark for humanitarian supply chains and also discuss the consequences of this study of cross-organizational learning on the scope of our work. To carry out this benchmark, we have designed a case study. Indeed, "the case study method allows investigators to retain the holistic and meaningful characteristics of real life events such as individual life cycles, organizational and managerial processes, changes in the neighbourhood, international relations and the maturation of industries" [Yin02]. This fits our purpose to assess the agility of supply chains. For this study, we gathered documents, archival records and twelve semi-directive interviews of practitioners working in various regions (Europe, Middle-East or Africa) and at different organizational levels (headquarters,

regional logistics centers or field workers). Chapter 6 on page 63 summarizes the evidence collected from the International Federation of the Red Cross and Red Crescent Societies (IFRC) ([Sec07]; [Sec08]; [Ols07] [Bus07]; [Jon08]; [Goo08]; [Zub08]; [Ryc07]), “Medecins Sans Frontières” (MSF) [Lab08] and the French Red Cross [Gre09]. Other organizations such as Oxfam and the World Food Program were also approached but with more informal interviews.

Finally, we will present our model for assessing supply chain agility, its construction and its implementation using a real life case study. To build the assessment model, we used a symbolic modeling approach. A symbolic model is a representation of the performance measure of a system in terms of its variables. This means that the attributes of the system are linked by an equation [Pan04]. In chapter 4 on page 51 we presented a list of attributes of supply chain agility and in chapter 7 on page 67 we will present a list of metrics associated to these capabilities, as well as a consistent method to evaluate and aggregate them.

5.2 Existing approaches for assessing the capability level of a system

There are two main approaches for assessing the capability level of a system: maturity assessment and performance evaluation. We have looked at the capability maturity model (CMMI®) used for assessing the maturity level of organizations, the European Quality Award (EQA) of the European Foundation for Quality Management (EFQM) used for auditing the quality competencies of companies and the Supply Chain Operations Reference model (SCOR model) used for measuring the performance of supply chains.

5.2.1 EFQM : assessment of quality management

The ISO 9000 norm defines quality as “the ability of a set of inherent characteristics of a product, system or process to fulfill requirements of customers and other interested parties” [AFN08]. Excellence with regards to quality management is rewarded by quality awards, such as the EQA in Europe. ISO standards and quality awards set quality requirements that an organisation has to meet to be certified. The EFQM model allows assessments to be made of organisations’ results using four result criteria (Customer Results, People Results, Company Results, Key Performance Results). It also judges what enables an organisation to achieve these results with criteria of five factors (Leadership, Policy and Strategy, People, Partnerships and Resources, and Processes) [EFQ09]. Criteria such as customer results or partnerships and resources are also essential for achieving agility. And yet, EFQM, in being too general, is far from being well-adapted to assess agility. Indeed, “the 2004 state of EFQM is not particularly focused on the capacity of organisations in terms of absorbing environment changes or on organisations with a project orientation” [MM07]. In its 2010 release though, the EFQM strengthened the attributes "speed" and "flexibility". It nevertheless remains fairly general and not focused on agility.

The EFQM model is not suitable for humanitarian organisations or for industrial sectors that are faced with frequent short-term changes. In both cases, the emphasis on strict procedures and their documentation may particularly go against agility. For these reasons, EFQM cannot be used in our specific case.

5.2.2 CMMI®: assessment of maturity level

As we have seen in the previous paragraph, EFQM is not usable in our specific case. As for the CMMI®maturity model, it follows a slightly different approach, which may seem more appropriate for assessing agility levels. Unlike quality standards that are internally focussed and define a standard that an organisation may achieve or not, maturity models define levels of maturity that organisations can use to evaluate their processes. The ISO 15504-7 norm, an assessment of organisational maturity, defines organisational maturity as the "extent to which an organisation consistently implements processes within a defined scope that contributes to the achievement of its business goals (current or projected)" [AFN08]. A maturity model is "a model that contains the essential elements of effective processes for one or more disciplines and describes an evolutionary improvement path from ad hoc, immature processes to disciplined, mature processes with improved quality and effectiveness" [Uni06].

Two representations of CMMI®may be used, either staged or continuous. Staged representation uses maturity levels to measure process improvement. These maturity levels apply to an organisation's overall maturity. Sets of pre-defined process areas outline an improvement path for the organisation. Continuous representation, on the other hand, uses capability levels to measure process improvements. Improvements are characterised relative to an individual process area. Based on its business objectives, an organisation selects the process areas in which it wants to improve and to what degree. Instead of maturity levels, capability levels ranging from 0 to 5 are used to measure improvement. This enables an organisation to implement process improvement in different process areas at different rates, but the path toward overall maturity improvement may be blurred. For example, an organisation may reach a capability level of 0 for one process area and a capability level of 3 for another.

Neither EFQM nor CMMI®can readily be used. The design of a specific model for agility capabilities is necessary as CMMI®has more than five hundred pages. This leaves little room for interpretation and makes it a time-consuming process, and therefore not usable in humanitarian organisations. Moreover, the emphasis on strict procedures and their documentation could lead to bureaucratic behaviour. It also aims to stabilise processes, which is not a fundamental characteristic of agile processes.

This thesis provides a model for particular application domains, i.e. organisations that have to cope with short-term changes in supply, demand or the environment. In our study, the focus is on supply chains instead of organisations and the highest level characterises a supply chain that achieves a high level of agility, i.e. that responds quickly and adequately to short-term changes in demand, supply or environment.

5.2.3 Performance measurement systems - SCOR model

Supply chain performance measurement systems, such as the SCOR model, use a language of common metrics with associated benchmarks and provide a platform for best-in-class comparison and inspiration [HSW04]. Some of the performance dimensions in the SCOR Model are required to achieve supply chain agility but the model cannot be used to assess agility either, for it focuses on transactional efficiency rather than on the relationship with customers and suppliers [LGC05].

Table 5.1: SCOR Performance attributes and level1 metrics [Cou06]

Level 1 Metrics	Performance Attributes				
	Customer-Facing			Internal-Facing	
	Reliability	Responsiveness	Flexibility	Costs	Assets
Perfect Order Fulfillment	X				
Order Fulfillment Cycle Time		X			
Upside Supply Chain Flexibility			X		
Upside Supply Chain Adaptability			X		
Downside Supply Chain Adaptability			X		
Supply Chain Management Costs				X	
Cost of Goods Sold				X	
Cash-to-Cash Cycle Time					X
Return on Supply Chain Fixed Assets					X
Return on Working Capital					X

5.2.4 Conclusion - construction of a specific model, inspired from existing tools

Finally, we believe that our quest to define a specific model for assessing agility represents a real need that neither quality awards nor actual maturity models (or performance measurement systems) can satisfy. Our proposition follows a similar approach as maturity models but the assessment is done on performance dimensions rather than on the completeness of the process implementation. This is because firstly, stabilized processes are not a fundamental characteristic of agile processes and secondly, processes are only one of the various areas to work on. People, products and partners are also elements that impact the capability levels (see Table 5.1). Actually, to be able to react quickly and adequately to short-term changes, specific processes are needed, but these processes should be able to move quickly from one stabilized state to another. Having them stabilized may help, for example, in terms of visibility, but it is not enough to achieve agility.

5.3 Existing models to assess agility : fuzzy logic

Our review of the literature showed three articles with models to assess the agility of organisations or supply chains, based on fuzzy logic [JBD08]; [LCT06a] and [Bot09].

Fuzzy logic is the precise logic of imprecision and approximate reasoning [Zad08]. More specifically, fuzzy logic may be viewed as an attempt at formalisation/mechanisation of two remarkable human capabilities. First, the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility – in short, in an environment of imperfect information. And second, the capability to perform a wide variety of physical and mental tasks without any measurements and any computations [ZK99].

The authors' main arguments for the use of fuzzy logic instead of any other method is that they find the attributes linked to agility assessment too qualitative and ambiguous [Lin09]. As a consequence, they propose in their approach to allow the use of subjective descriptions using linguistic terms, which indeed cannot really be handled effectively using conventional assessment approaches. Our approach complements theirs as we propose to adapt the metrics rather than the assessment methods. Our model, with questions that are less open than theirs,

facilitates the assessment as it limits the cases where interviewees do not know what they should answer. It also fills one of the limitations expressed by Lin, who recognises that further research is necessary "to compare the efficiency of different models for measuring agility" [Lin09].

The final advantage of our approach is also its easy usage. Explaining the results of the assessment to companies may not be straightforward when we look at the complex algorithm proposed by [JBD08], for example.

5.4 Conclusion : construction of a specific model, but without reinventing the wheel

We believe our quest to define a specific agility model meets a real need, that neither Quality Awards nor actual maturity models or performance measurement frameworks are answering. Our model follows a similar approach than maturity models. It focuses on assessing supply chain agility levels. Yet, the assessment is done on performance dimensions instead of the completeness of process implementation because stabilized processes are not a fundamental characteristic of agile processes. Indeed, to be able to react quickly and adequately to short term changes, you need specific processes in place, but you also need to be able to modify your processes, to jump from one stabilized state to another quickly. Having them stabilized may help in terms of visibility for example, but it is far from sufficient to achieve agility.

6

Humanitarian supply chains: the experience of uncertainties

6.1 Scope of our study

The notions of change and uncertainty that we have previously discussed are closely connected to that of agility. Uncertainties are omnipresent in the humanitarian world. There are many occasions where humanitarian supply chains have to develop their agility capabilities and they often do that successfully. One has to pay close attention to the elements that distinguish humanitarian supply chains from commercial supply chains in order to transfer the best practices of the former to the latter. Because of the differences, studies of the agility capabilities of humanitarian supply chains need to be filtered and adapted before they can be used in the business sector (see table 2.1 on page 29). First, our study will focus on the whole supply chain, except the manufacturing part, since it is irrelevant both from a humanitarian point of view and from an academic perspective (see chapter 4 on page 51). Secondly, we focused on suppliers and end users, but not on donors. We also did not consider the manufacturing part, thereby focusing on the elements that are common to most supply chains.

Lastly, our study focusses on the assessment of agility and helps to visualise a path toward improvement. The assessment of the most appropriate level of agility for a given supply chain is also needed to complement our approach. Indeed, relief chains have a short life cycle and are set up under specific conditions, thus facing more uncertainties. They therefore require a high level of agility. Not all commercial supply chains require such agility capabilities [Hun+99]. Consequently, a clarification of the level of agility needed for a given supply chain is required prior to any cross-learning implementation. Such a study may be inspired from Weber, who proposes a tool for measuring an organisation's need for agility [Web02].

6.2 Case Study : Humanitarian methods to achieve supply chain agility

The next step in the development of our assessment model entails creating explicit humanitarian methods that enable to achieve supply chain agility. David Kaatrud, former Chief of Logistics for the United Nations World Food Program (WFP), explains that in comparison to

the business sector, their "operational settings are typically very different and difficult, and to get supplies to the most remote areas, we may have to resort to a range of imaginative and unconventional delivery systems, from air-dropping to using elephants for transport" [TW09].

Many operations abound with examples where humanitarian agility has been demonstrated. Take the 2002 food crisis in southern Africa, for example. "In the middle of WFP's operation to send food to the most affected areas, news broke that the food, mostly donated by the US Government, was genetically modified. Many African countries refused the food" [TW04]. Demand had changed. With the fear of contamination of their fields, GMO was no longer an option, even if it meant a delay in getting food supplies. As a consequence, WFP ended up with tons of food that no longer satisfied demand. They had to deal with the stranded shipments and find some place to store the cargo while also minimising the wastage caused by humidity. And all this in addition to the cost of replacing the genetically modified food with non-genetically modified alternatives.

In the end, the organisation moved quickly and decided to mill the genetically modified food. However, large-scale milling had not been foreseen and had new implications for the operation. WFP had to incorporate the milling process with new distribution routes, a bagging process and storage. This limited the type of transportation that could be used and therefore also increased costs. However, WFP was able to turn what at first assessment seemed a negative situation into a positive one. For example, milling the genetically modified maize meant that they could add much-needed vitamins and minerals to boost the immune systems of those weakened by HIV. It also had wider implications, as local mills that had stood empty for many years were reopened, creating employment and encouraging regional purchases which, in turn, stimulated the economies of African countries [TW09]. This provides a clear example of a humanitarian organisation managing to respond quickly and adequately to short term changes.

They also developed specific tools to better monitor their supply chains and enable a quicker response to changes. The Humanitarian Logistics Software (HLS), for example, enables the International Federation of Red Cross (IFRC) to increase its supply chain visibility. Similar logistics software, such as HELIOS, the second generation of HLS or SUMA (SUpply MAnagement) is in use or under deployment in other agencies, namely Oxfam and World Vision International for HELIOS and the World Health Organization (WHO) for SUMA. Specific platforms for sharing information have also been developed. ReliefWeb, the website of United Nations Joint Logistics Center (UNJLC) or Humanitarian Information Centers allow various stakeholders to use the information given to build their knowledge of the situation and, with it, take effective action in the field [TW05b].

Short term changes are thus humanitarians' daily routine. To cope with uncertainties, they have developed quite a good number of methods. Whereas most of them are widespread in many organizations, others are not so commonly used. To help humanitarians formalize those practices and enable the business sector to draw from them, we have designed and conducted a case study research as earlier explained. The methods used by the IFRC to quickly respond to changes are shown in table 6.1 on the next page. A reference to the corresponding methods that are listed in the literature is added. It is inspired from [Lee04]; [HHC01]; [SGM06] and [LCT06b]. Surprisingly (or perhaps not), majority of the methods found in the literature are applied in the humanitarian sector. Those that cannot be found have no application for humanitarian supply chains since they concern agile manufacturing.

Table 6.1: Capabilities of the IFRC's supply chain, that enable them to develop their agility

Capability	Why	How	Corresponding methods found in literature
Volume Flexibility	The amount of relief items/people sent in the field depends on donations, often unforeseeable. It also depends on needs, which are only known after the crisis and assessed in parallel with the setting up of the supply chain.	Creation of the disaster response emergency fund (DREF) and other buffer funds allowing to start responding before receiving donations. Pre-training of teams of experts sent to field within 24h to assess needs. Presence of regional stocks, with capacity to provide relief items within 48h to 40000 families in total (stock capacity is adjusted per region)	Organize work force in self directed teams [HHC01] Adjust worldwide storage capacity [SGM06]
Delivery Flexibility	Little or no visibility on delivery planning, depending on the arrival of unsolicited in kind donations, etc.	Development of clear systems and procedures, job descriptions, etc. Creation of tailor-made software enabling pipeline time reduction and pipeline reports editions. Assessment of all available delivery modes made by logistician team in the field.	Alter delivery schedules to meet changing customer requirements [SGM06] Change delivery modes when necessary [SGM06]
Mix Flexibility	Depending on the affected area and the nature of the crisis, many different products have to be handled.	Standardization of as many emergency items as possible: emergency item catalogue with specifications and references of all items, that might be of use (around 7000 ref. for the IFRC) Creation of tailor-made software enabling the edition of mobilization tables, etc. for every crisis.	Increase level of customization [SGM06] Promote flow of information with suppliers and customers [Lee04]; [LCT06b]
Product Flexibility	In kind donations may not correspond exactly to the specifications. New needs may arise, that require specific items to be delivered.	Continuous work on an emergency item catalogue to make sure specifications and references of all items are known in advance and up to date. Experts trained at assessing the quality of products received by suppliers.	Fast introduction of new products [LCT06b]

Continued on next page

Capability	Why	How	Corresponding methods found in literature
Reactivity	Needs of beneficiaries evolve constantly.	Experts in need identification and evaluation are present in many regions. Pre-trained teams in field assessment are ready to deploy in case of emergency.	Organize work force in self directed teams [HHC01] Draw up contingency plans and develop crisis management teams [Lee04] Virtual integration (instantaneous demand capture, interpretation and response) [HHC01]; [LCT06b]
Velocity	Many tools and methods have been developed to accelerate the setting up of the supply chain and allow it to evolve with needs.	Pre-positioning of emergency relief items. Framework agreements with suppliers. Development of tools enabling faster response in the field (mobile warehouses, teams of pre-trained experts with their specific materials (logistics, water and sanitation, telecoms, etc.)	Adjust worldwide storage capacity [SGM06] Have a dependable logistics system or partner [Lee04] Develop collaborative relationships with supplier [Lee04]; [LCT06b] Organize work force in self directed teams [HHC01] Facilitate rapid decision making [LCT06b]
Visibility	The complexity of the environment makes it really difficult to have a clear vision of what stakeholders are doing.	Creation of a tailor made software enabling a better monitoring of the response (HLS / HELIOS), a software to manage stocks (LOGIC), some balanced scorecards, etc.	Information accessible supply chain wide [LCT06b]
Reliability	Delivering the adequate aid may be a question of life or death for the beneficiaries	Use of an emergency item catalogue to make sure specifications and references of all items are known and validated by potential beneficiaries. Products and kits are modified depending on the areas. (winter tents or just mosquito nets for shelter ; medicines and clothes in agreement with local customs and laws, etc.)	Customer sensitivity (customer centred logistic policy) [HHC01] Design for postponement [Lee04]
Completeness	Basic needs not fulfilled may result in deaths.	Keep track of number of families being assisted	Measurement [HHC01]

7

Supply chain agility assessment model

7.1 Metrics

7.1.1 Literature review and list of metrics

As we mentioned earlier, humanitarian and commercial supply chains differ on many points. Therefore, for the transfer of best practices to be relevant, we need to focus on the agility metrics that are relevant for both supply chains. This leads to a fundamental question: how can agility capabilities be assessed in a consistent manner?

With reference to chapter 4, the agility of a supply chain is derived from its flexibility, responsiveness and effectiveness. Some agility metrics can be found in the literature ([HHC01]; [Sla05]; [Oko+08]; [KMS95]; [ND99]; [SS90]; [KS09]). Unfortunately, most of the metrics listed are not relevant for humanitarians since they usually focus on the manufacturing part and deal with the production of goods. We have thus refined the tables such as to list only agility indicators that are relevant for both sectors, hence dropping the metrics that are used to assess manufacturing agility (see Table 7.1 on the following page).

7.1.2 Importance of people, process, product and partners

Many elements impact the capability of a supply chain to be agile. Having the right processes defined and implemented is obviously necessary if a supply chain wants to ensure what could be called a given level of maturity in terms of agility. Though primordial, processes are not sufficient to ensure agility. (see section 5.2 on page 58) We have therefore retained four different categories that have to be worked on:

- Processes = Design and management of supply chains, information systems
- People = Human resources, their presence, training, organisation and team effectiveness
- Products = Innovation, customisation
- Partners = Customer and supplier involvement and agreements

Each of these categories has its associated metrics.

Table 7.1: List of metrics

Metrics	Capabilities	Reference
Extent to which supplier lead time can be expedited/changed	Volume flexibility	[ND99]
Extent of flexibility options within supplier contracts	Volume flexibility	[ND99]
Number of suppliers selected per component on a global basis	Volume flexibility	[KMS95]
Number of components purchased per supplier	Volume flexibility	[KMS95]
Range of possible order sizes from suppliers	Volume flexibility	[SS90]
Number of end users supported by each distribution facility, on average	Volume flexibility	[SS90]
Adequacy between worldwide storage capacity and needs	Volume flexibility	[SS90]
Adequacy between global delivery capacity and needs	Volume flexibility	[SS90]
Number of items handled by each distribution facility, on average	Mix flexibility	[SS90]
Number of items per order handled by each distribution facility, on average	Mix flexibility	[SS90]
Number of worldwide storage/distribution facilities	Delivery flexibility	[SS90]
Percentage of user orders filled from alternate global facilities	Delivery flexibility	[SS90]
Number of adequate available delivery modes	Delivery flexibility	[SS90]
Number of carriers used for each type of delivery mode, on average	Delivery flexibility	[SS90]
Delivery lead times	Delivery flexibility	[HHC01]
Level of customization	Product Flexibility	[HHC01]
Intermediate user [and end user] involvement in writing products specifications	Reliability	[HHC01]
Percentage of the demand fulfilled within acceptable time frame	Completeness	[Oko+08]
Percentage of workforce in self directed teams	Velocity	[HHC01]
Number of organisational levels	Velocity	[HHC01]
Authority level at which risks can be taken and decisions are made	Velocity	[HHC01]
Presence/ exhaustiveness of contingency plans	Velocity	[CLW10]
Number of emergency response teams	Velocity	[CLW10]
Frequency of intermediate [and end user] needs assessment	Reactivity	[KS09]
Availability and diffusion of information regarding identity, location and status of entities transiting the supply chain people, items, etc.	Visibility	[HHC01]

Legend People Process Product Partner

7.2 Assessment grids

From these metrics, an assessment of the agility capabilities of the supply chain has to be deduced. For this specific purpose, we used a symbolic modeling approach. The idea is to use the above metrics to measure each capability. They will enable to qualify the supply chain to a given level for each capability, using evaluation grids such as the one suggested in Tables 7.2 and 7.3 on page 71. Grids for the evaluation of other capabilities are presented in appendix. As we can see in those Tables, supply chain agility metrics are linked by equations in order to enable a consistent assessment of each capability. Supply chain agility can then be deduced from the previous scores on the basis of the model exposed in Table 7.4 on page 72. The method used to build these equations is similar to the one used to build the CMMI®Maturity Model: brainstorming and validation by practitioners. To conduct an overall assessment of supply chain agility, each capability (flexibility, responsiveness and effectiveness) has to be evaluated through its evaluation grid. Special care has been taken to keep it as robust and reproducible as possible.

To illustrate how to use the model, we conducted an assessment of the agility of IFRC's relief chain during its response to the 2006 Yogyakarta earthquake. The detailed scores of the responsiveness of IFRC's supply chain correspond to the darker cells in Table 7.3 on page 71. The overall assessment is summarized in table 7.4 on page 72. To increase the visibility of both results and path forward, these results can be presented in the form of a radar graph, as shown in Figure 7.1 on page 74. On the 0 – 3 scale for the capability levels, we can see that IFRC scored 3 on velocity, 2 on reactivity and 1 on visibility. Indonesia being used to natural disasters, its National Society has developed contingency plans and the local delegation fosters a Regional Disaster Response Team, a trained team of experts with pre-prepared field equipment, including computers and telecommunications. These teams are deployed from the region and are therefore more likely to point out local specificities and adequately evaluate the needs of beneficiaries. They helped increase reactivity. IFRC has also developed units to respond to specific needs, for example, IT and telecommunications, and referral hospital or logistics. Dispatching these units definitively contributed to increasing velocity and reactivity levels. Consequently, IFRC's velocity and reactivity levels are quite high. Regarding visibility, IFRC scored only 1 for this specific operation. Actually, following their decentralization process, they had a system in place to track the location and status of goods at the regional level. Since it was their first operation with such an organization, the information flow was not optimal. During the first days of the operation, there was no tracking system in place. They had parallel pipelines, which hindered visibility and reporting lines were not clearly defined.

7.3 Assessment method

The aim of the evaluation grid proposed in Tables 7.2 on the next page and 7.3 on page 71 is to assess the velocity, and then responsiveness of supply chains, once a similar table for visibility and reactivity is filled to complement the assessment grid for velocity. Other similar tables have been built to assess the overall agility level. To make the best out of it, it should not be used without a method that should provide organizations with instructions on how to use it, as well as improvement paths that would enable to achieve higher levels in the grid. The assessment of supply chain agility starts with the preparation phase, where the person in charge of the audit selects the participants to be interviewed, selects and prepares the assessment team and develops the assessment plan. The second phase consists in conducting the assessment. To do this, interviews, records and documentation are used to gather relevant information

Table 7.2: Assessment of Supply Chain Velocity - Grey cells correspond to our assessment of IFRC

		Score = 0	Score = 1	Score = 2	Score = 3
Velocity, 5 metrics	Percentage of workforce in self directed teams	Less than 20% of workers are organized in teams	Between 20% and 60% of workers are organized in teams	Between 60% and 80% of workers are organized in teams	More than 80% of workers are organized in teams
	Number of organisational levels	More than 6 organisational levels	5 or 6 organisational levels	3 or 4 organisational levels	Less than 3 organisational levels
	Authority level at which risks can be taken and decisions are made	No authority at field level	Field workers have to wait for the person in charge of them to approve before acting	Significant changes need approval from hierarchy	Worker can act if necessity is there
	Presence/ exhaustiveness of contingency plans	No contingency plan exists	Presence of a contingency plan, but rough	Presence of a contingency plan, but not sufficiently detailed	Presence of an exhaustive contingency plan
	Number of emergency response teams	No emergency teams	Some emergency teams, but just enough to cope with less than 50% of uncertainties	Some emergency teams, but just enough to cope with 50 to 90% uncertainties	Enough emergency teams to cope with uncertainties
Assessment of Supply Chain Velocity		$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 5$	$5 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 10$	$10 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 14$	$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) \geq 14$

Table 7.3: Assessment of Supply Chain Responsiveness - Grey cells correspond to our assessment of IFRC

		Score = 0	Score = 1	Score = 2	Score = 3
Velocity	Overall assessment of Supply Chain Velocity, from previous table	Workers are individuals, having no authority to take risks.	At least 20% of workers operate in self directed teams having mandate to deal with small size risks.	At least 60% of workers operate in self directed teams having mandate to deal with medium size risks.	Supply chain management is responsibility of teams.
Reactivity	Frequency of intermediate and end user needs assessment	Neither intermediate nor end use needs are assessed	Intermediate user's need are assessed on a yearly basis. No assessment of end user needs	Intermediate user's need are assessed on a monthly basis. End user needs at least once a year	Evaluation and assessment of all user needs is done on a weekly or daily basis
Visibility	Availability and diffusion of information on entities transiting the supply chain	No systematic capture of information.	Information about people and products is captured, but not circulated.	Information about people and products is captured, but only partially circulated	Supply chain is structured around information flow
Responsiveness	Overall assessment of Supply Chain Responsiveness	$\sum \begin{pmatrix} Scores\ of \\ Velocity \\ Reactivityl \\ Visibility \end{pmatrix} < 3$ Supply chain is not able to respond to change within an appropriate time frame	$\sum \begin{pmatrix} Scores\ of \\ Velocity \\ Reactivity \\ Visibility \end{pmatrix} \geq 3$ Supply chain is able to respond to some changes but not within an acceptable time frame	$\begin{cases} Velocity\ level \geq 2 \\ Reactivity\ level \geq 2 \\ Visibility\ level \geq 1 \end{cases}$ Supply chain is able to respond to most changes, usually within an acceptable time frame	$\begin{cases} Velocity\ level = 3 \\ Reactivity\ level = 3 \\ Visibility\ level \geq 2 \end{cases}$ Supply chain is able to respond to any change within an appropriate time frame

Agility level 5
Flexibility = 3
Reactivity = 3
Velocity = 3
Effectiveness = 3
Visibility ≥ 2

Agility level 4
Flexibility ≥ 2
Reactivity ≥ 2
Velocity≥ 2
Effectiveness ≥ 2
Visibility ≥ 1

Agility level 3
Flexibility ≥ 2
Reactivity ≥ 1
Velocity≥ 1

Agility level 2
Flexibility ≥ 1

Agility level 1
Flexibility < 1

Table 7.4: Assessment of Supply Chain Agility

Key Improvement Area	Capability Level 0	1	2	3
Volume Flexibility Delivery Flexibility Mix Flexibility Product Flexibility Reactivity Velocity Reliability Completeness Visibility	Agility Maturity 1	Agility Maturity 2	Agility Maturity 3	Agility Maturity 5
		Agility Maturity 4		

and generate results. Once the results are validated, the final report can be delivered and documented. The final step consists then in developing the improvement plan, with the aim of achieving the desired levels for all capabilities.

Table 7.5: Assessment method

1. Prepare assessment Familiarize with maturity model Select participants Develop assessment plan Select and prepare assessment team
2. Conduct assessment Conduct interviews Study records and documents Document and verify gathered information Generate and validate assessment results
3. Finalize assessment Deliver final report and document assessment (Filled assessment grids and Radar graph)
4. Plan for improvement Select and prioritize improvement initiatives Develop improvement plan

To design the improvement plan, two options are open to the organization. Either it focuses on

Table 7.6: IFRC Agility Assessment - Summarized results

Key Improvement Area	Capability Level 0	1	2	3
Volume Flexibility			X	
Delivery Flexibility			X	
Mix Flexibility			X	
Product Flexibility			X	
Reactivity			X	
Velocity				X
Reliability			X	
Completeness				X
Visibility		X		

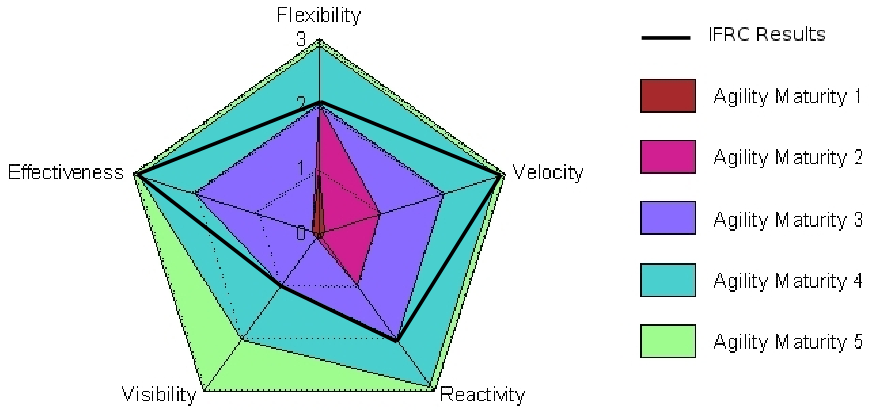
the capabilities with the lowest score or it focuses on sets of pre-defined capabilities depending on its current and desired agility level. The first option enables an organization to implement process improvement in different process areas at different rates. The capabilities that the organization wants to focus on are evaluated independently using their specific evaluation grid, for example, Table 7.3 on page 71 for the assessment of responsiveness. The second option is illustrated in Figure 7.4. To use it, each capability has to be assessed with its evaluation grid. The results are then aggregated to qualify the supply chain to a given level of agility. There are 5 levels of overall agility (Ad Hoc, Repeatable, Defined, Managed and Optimized) and 4 levels for each capability that can be assessed thanks to the metrics defined in the previous section. A rough correspondence between agility maturity and capability levels is illustrated in Figure 7.4. The improvement path may be either increasing a given capability (depending on the organization's strategy) or increasing the overall agility level by targeting a given profile. For example, an organization that has achieved a capability level of 2 on all dimensions (flexibility, reactivity and velocity) may want to increase its agility level by working on its reliability and completeness.

Let us now go back to our previous application – the IFRC solution to the 2006 Yogyakarta earthquake. Figure 7.1 shows the summarized results of this example.

7.4 Guiding Thread 3 Assessing supply chain agility during Jogjakarta's operations

As we can see in the figure, IFRC achieved capability levels of 2 for flexibility, reactivity and reliability, 3 for velocity and completeness and 1 for visibility. Consequently, its agility level is ranked 4 (Managed) for this relief operation. A realistic improvement plan should first be discussed with the IFRC management team in order to validate the desired level. One recommendation that ensues from these results could be to start by improving the flexibility of the supply chain thanks to an improvement of their supply chain design. They can also improve their reactivity by coordinating with other organisations to pool field assessment reports. Finally, visibility could be increased thanks to the rework of their information system in order to enable the tracking and spreading of information about nature, number and status of entities transiting through the end to end supply chain. This would include a tracking system for the last mile delivery of items.

Figure 7.1: IFRC Agility Assessment - Radar graph



This is the first application of our model. Further research is underway to use this tool in other situations. In the case of project-oriented supply chains, as is the case for the humanitarian and some industrial sectors, the study can be carried out in two ways:

- For a single organization, assess the agility of the supply chain in multiple projects in order to evaluate the consistency, evolution, min, max and average level of their supply chain agility.
- For a given type of project, assess the agility of the supply chain of various organizations. For example, how well did various organizations perform during the 2009 hurricane season in the Caribbean?

Such a study will enable to identify best practices and gaps, first steps toward self-improvement and opportunities for the transfer of best practices.

7.5 A practical tool to facilitate the assessment

To facilitate the assessment and the analysis of results, an application in MS Excel has been developed. This provides a quick and user-friendly utilisation of our model.

Figures 7.2; 7.3 and 7.4 provide a brief overview of its added value.

As you can see in figure 7.4 on page 76, an analysis of the results for one organisation, as well as a comparison of various organisations, are possible. This figure illustrates some of the possible dimensions for the analysis. Others are also available, specific to humanitarian organisations, to private companies or usable by both.

Figure 7.2: Main page of the tool

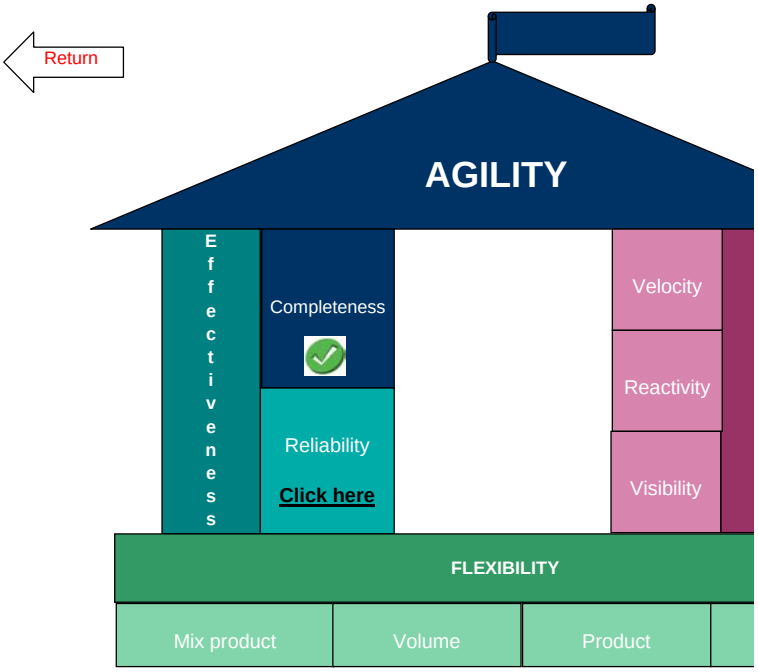


Figure 7.3: Assessment of Reactivity

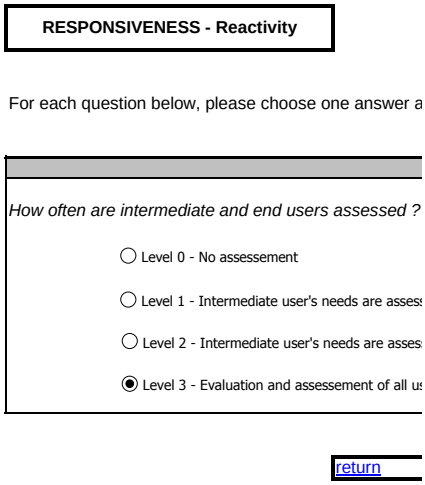
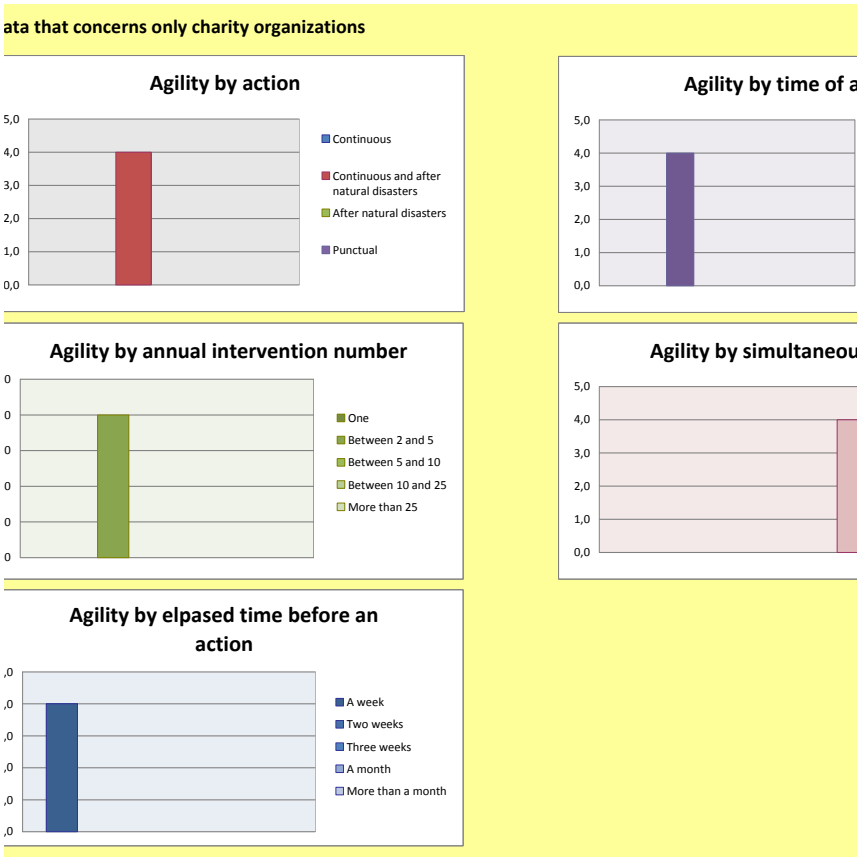
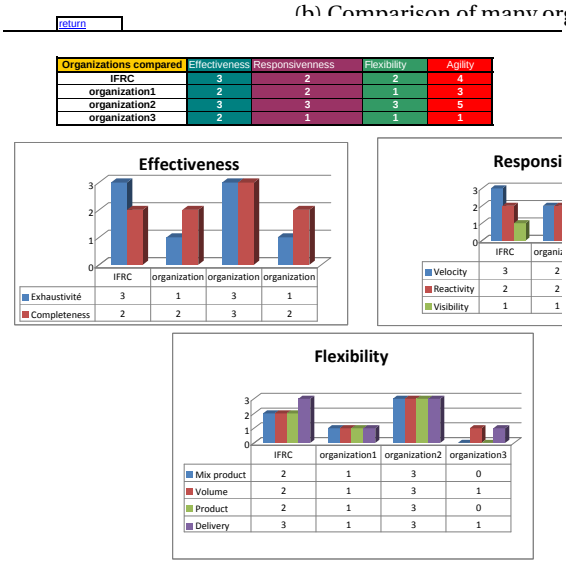


Figure 7.4: A few examples of potential analysis and comparisons

(a) Comparison of many organizations - Analysis



(b) Comparison of many organizations - Agility results



Conclusion and Perspectives

As we have shown is this thesis, humanitarians have developed tools and methods to quickly respond to changes. Yet, especially in the humanitarian context, it is hard, if not impossible, to extensively develop some of the agility capabilities enumerated in chapter 4 on page 51. Total visibility, for example, is not easily achievable by humanitarians, for not only there is usually no single entity responsible for the whole supply chain, but also there are few systems in place to share information between all the actors of the end-to-end supply chain.

On the other side, given the highly competitive and uncertain business environments in which they operate, commercial supply chains constantly search for new ways of developing their agility capabilities in order to improve their competitiveness and profitability. Thus, supply chain agility is a strategically important capability in many sectors, including the humanitarian.

The contributions of this part are twofold. First, it provides a framework, represented in the form of a House of Supply Chain Agility, that enables to understand the notion of supply chain agility. Secondly, it develops a model for assessing the agility of a supply chain. The expertise of humanitarians in the field of supply chain agility is used to suggest some systematic methods used to achieve a high level of agility. We also propose some metrics and a proceeding method that can be used to evaluate supply chain agility. All this will constitute a basis for future field research, with the aim of identifying and transferring best practices in supply chain agility. This work will therefore be followed by field applications for various humanitarian relief operations as well as for some commercial supply chains.

Finally, by making explicit the performance dimensions of agility, we also underlined areas to work on, should a supply chain want to improve its agility level. As we have shown, to achieve a high level of agility, the adequacy between storage and delivery capacity and needs, the delivery lead times and the percentage of demand fulfilled within acceptable time frame are vital. So are the number of worldwide storage/distribution facilities and the availability of adequate transportation modes. All in all, there are 11 out of 24 metrics, that are linked with how the supply chain is configured (see figure 7.5 on the following page). The last part of this thesis will therefore focus on the design of logistics networks under high level of uncertainties regarding supply, demand or environment.

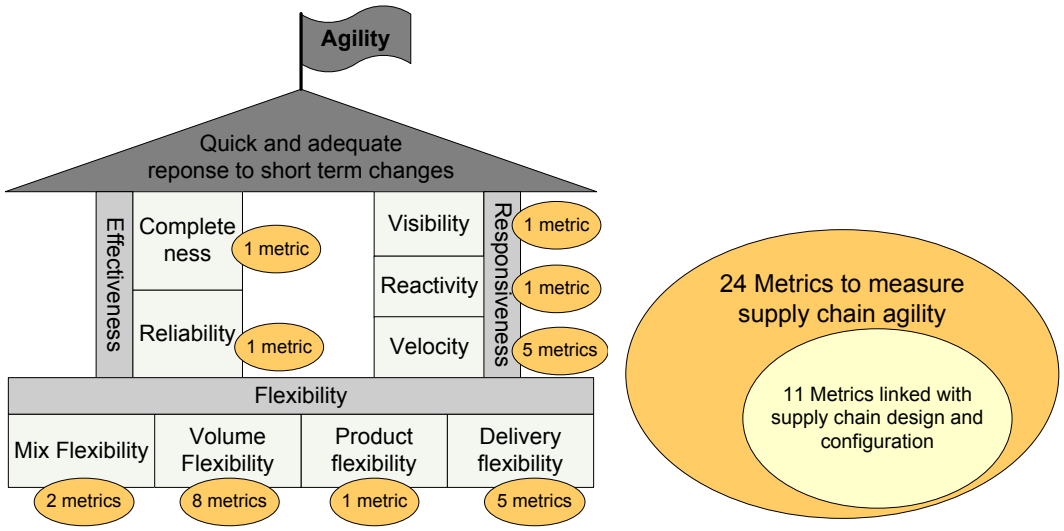


Figure 7.5: Why focusing on the design of agile supply chains?

PART III

Supply Chain Network Design

Purpose: As agility often depends on the adequacy between delivery capacity and needs, this part aims at designing a logistics network under high levels of uncertainty, so that for a given level of service in terms of agility, it maximises its efficiency. Our study quantifies the impact on costs of various decisions, such as network centrality, supply strategy and level of service. We therefore provide some recommendations, aiming at helping humanitarian organisations to define their logistics strategy.

Design/methodology/approach: Methods used for this research are mathematical modelling and literature review.

Findings: Many factors can influence the number and location of warehouses where stock should be pre-positioned to enable a quick response to disasters at lesser costs. Some regions, such as South-Central Asia can nevertheless be pinpointed as optimal places to hold a warehouse, whatever the conditions.

Research limitations: We limited our study to the most important issues faced by humanitarian organisations. Many research perspectives, such as the study of specific resources (vehicles, human resources) are still open. Additional runs to validate the robustness of the model as well as its sensitivity to data and parameters with more precision are currently underway. A field validation of those results with humanitarian organisations would also be required.

Originality and value: We have designed our study on the basis of input from and discussions with humanitarian practitioners. Uncertainties with regards to demand and supply have also been considered. Local parameters have also been taken into account in order to minimise environment uncertainties. This quantified analysis about the decentralisation of a supply

chain, its motivations and the importance of each decision variable are of prime importance in our globalised world, for any line of business.

Introduction

Competitiveness also exists in the humanitarian world. Flexibility, responsiveness and effectiveness are essential in order to respond to the needs of the beneficiaries. They could be taken as the “order-qualifiers” of humanitarian response. As for “order-winner”, efficiency is increasingly favoured by donors as a means of ensuring the money they give is used in an optimum manner. Whereas speed and effectiveness have already received a lot of attention from humanitarian organisations, efficiency has still to be worked on.

As we have seen previously, 30 to 50% of what enables an organisation to be agile is closely linked with its supply network. This part will therefore focus on this specific component of supply chain agility by designing and dimensioning a network aimed at ensuring a desired level of agility in the most efficient way.

Up until now, humanitarians have on the majority of occasions used existing opportunities as a means of configuring their logistics networks. They build their stocks where they already have people working or where a "good spot" has been found; like proximity of an airport or special agreements with a country with regards to its custom procedures and taxes. By failing to think a little more about what else is available, they are consequently narrowing their options and often missing out on better locations. They can also choose a location based on criteria that may not be the most relevant. Some work has already been done in this area (WVI GPRN[1], CARE USA work with Georgia Tech, FEMA[2] studies) but all are tailor made and few are published, which hinders transfer of best practices. Moreover, they usually focus on relief items pre-positioning, forgetting human resources and vehicles, and usually maximise effectiveness, not efficiency.

Our proposition is to help humanitarians to configure their logistic network so that for a given level of service in terms of reactivity and completeness, they improve their efficiency. This would be done through a deeper analysis of the optimum locations for their resources to be held. To optimise the location and dimensioning of resources, we need to:

- Analyse how things are currently done, and why (see chapter 8 on page 83)
- Motivate our approach, by making explicit the drivers for pre-positioning resources on a local level (see chapter 9 on page 91) and for using OR[3] methods to design a logistics network (see chapter 10 on page 97)
- Model future demand, taking into account changes in disaster trends and other influential factors like urbanisation (see chapter 11 on page 103)

[1] World Vision International, Global Pre-positioning Resource Network
[2] Federal Emergency Management Agency
[3] Operations Research

- Make explicit the targets to be met, the constraints and the objective (see chapter 12 on page 113)
- Analyse the results and the sensitivity of the model (see chapter 13 on page 123)
- Provide a decision-support model to choose within the regions the best country to open a warehouse (see chapter 14 on page 149)

Many humanitarian organisations have recently reorganised their logistics networks or are currently in the process of thinking about it. Care USA, World Vision International, the IFRC[4], MSF[5] or WFP[6] and other UN agencies have expressed their concern with, along with an interest in, facility location problems. They ask questions such as: “What stock should we hold? How much and where? How should it be managed and how do we ensure what we think is needed matches the needs of logistics’ primary stakeholders?” [IFR07b]

These are common questions among the international disaster relief community. This problem is therefore an interesting one, and worth taking a look at, both because of its impact on agility and because of its importance for many humanitarian organisations. Our aim is to help NGOs[7] to answer those questions by providing a quantified analysis of their logistics network.

As there are already many warehouses in existence all over the world (see chapter 8), we provide a model, which enables them to answer such questions as "What is the optimal network configuration (one or two stages)? How many warehouses should we have? Where? Which size? What would be the impact of various supply strategies on the design of the network?" We will first provide elements to answer these questions in a situation where we do not take existing warehouses into account. We will then focus on one existing network and discuss its design, making explicit the comfort zones, for which the actual network is fine, and providing input that will help decide if new warehouses should be added, or if existing ones should be relocated or closed.

For information purposes, IFRC’s[8]biggest warehouse is no more than 3000m^3 and has only 10 employees, so in relocation terms there would be limited social and economic impact. From an academic point of view, the problems of facility location are a huge area of research. Humanitarians’ constraints and uncertainties are not only interesting to tackle because of their complexity, but also because of their potential value for the private sector. They will also give insights regarding how to deal with supply, demand and environment uncertainties.

The idea is to build a model usable by any organisation; that is easily customised, and takes into account each organisation’s specificities. As input includes localisation of suppliers for example, we have based our analysis on the IFRC network.

[4] International Federation of the Red Cross and Red Crescent Societies
[5] Medecins sans Frontieres - Doctors without Borders
[6] World Food Program
[7] Non Governmental Organisations
[8] International Federation of the Red Cross and Red Crescent Societies

8

Overview of actual logistics networks

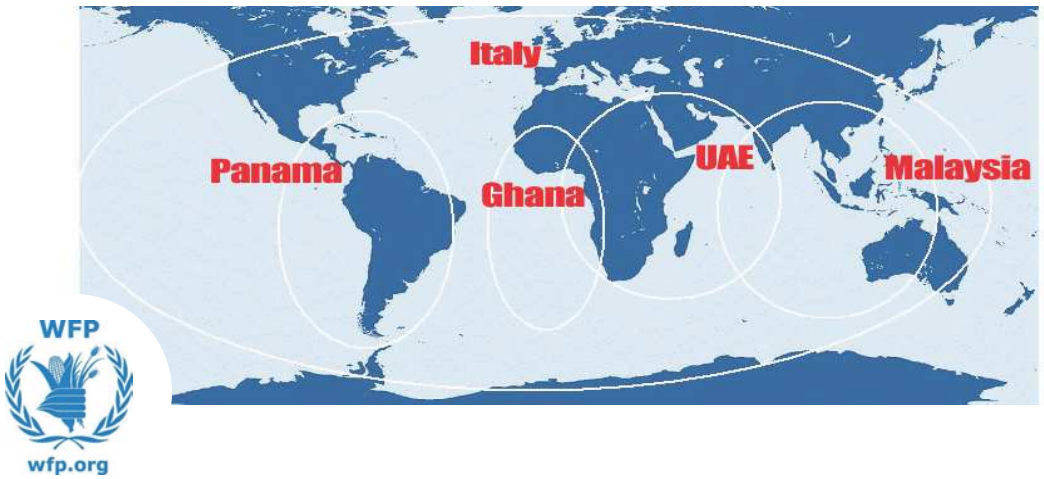
8.1 The United Nations Humanitarian Response Depot

Since 2000, the UNHRD[1] has consisted of five warehouses located in South Europe (Brindisi / Italy), Western Africa (Accra / Ghana), Western Asia (Dubai / UAE), South Eastern Asia (Subang / Malaysia) and Central America (Panama City / Panama). Up until now, their largest warehouse was in Italy, covering 15150m^3 in total (open + covered space, including cold room). Dubai, currently covering 10,000m^3, is being relocated to a much bigger place, where 120,000m^3[2] in total will be available to store relief items. They are managed by the WFP[3], who maintain both HRD's[4] Programme and Operational Support Stock.

Many other organisations have signed agreements to link their networks with the UNHRD. They have specific procedures for both release and stock management. Most of the time, they maintain their stock in Italy. Various organisations, such as OCHA[5], WHO[6], INTERSOS[7], UNJLC[8], GOAL[9], DGCS[10] for example maintain program and/or operational stock at Brindisi. WVI[11] is the only organisation, to maintain stock at Brindisi as well as in other depots like Dubai. Initially, WVI's global prepositioning network (GPRN[12]) was independent from UNHRD, but in the last two last years they have become linked. UNHRD is also managing, under a full cost recovery system, a stock of Non Food Items and Rapid Response Equipment stored by the suppliers. The release of this stock is approved by the UNHRD Network Coordinator. There isn't anything available to explain the overall decision process in detail, but some criteria have been given in different UN reports and websites regarding the choice of location: According

[1] United Nations Humanitarian Response Depot
[2] figure provided by UNHRD website - http://www.unhrd.org/?page_id=99
[3] World Food Program
[4] Humanitarian Response Depot
[5] Office for the Coordination of Humanitarian Affairs
[6] World Health Organisation
[7] Independent NGO established in 1992 with the active support of Italian Trade Unions
[8] United Nation Joint Logistics Centre
[9] International Humanitarian Agency founded in Dublin in 1977
[10] Directorate General for Development Cooperation (Italian)
[11] World Vision International
[12] Global Pre-positioning and Resource Network

Figure 8.1: United Nations' Humanitarian Response Depots (UNHRD)



to the UNICEF website, each of the following elements are to be taken into account: ability to respond to emergencies within 48hrs, quality of infrastructure, effective delivery systems, sound management, supply base quality, and cost effectiveness. Other UN websites and reports provide additional criteria (see table 8.1 on the facing page)

They would like to build additional warehouses, mainly in Africa and South East Asia. For Africa, where aid demand is high and inland transport weak, they intend to open 5 depots. As for Asia, locations such as Singapore, Beijing, or Tianjin may see a depot opening in the near future. Some details regarding the choice of their Asian depot can be found in table 14.4

8.2 Situation at the IFRC

8.2.1 Relief Items

In 2006, a budget of CHF6 million (€4million) was approved by IFRC's management team to set up 3 RLUs[13] so that they could decentralise operational capacity. Three locations were then chosen for the RLUs. Dubai was to cover Europe and Africa, Kuala Lumpur was chosen to cover Asia and Australia, and PADRU's[14] Panama location was maintained to cover America.

A number of factors were taken into consideration when making this choice. First of all, these sites already had extensive IFRC presence, such as the Fleet Base in Dubai, the Asia Pacific Service in Kuala Lumpur, and PADRU in Panama. Other elements, such as political factors or the locations' accessibility to the areas that each RLU would cover also had to be considered. In Dubai, for example, the RLU would benefit from proximity to Jebel Ali, the world's largest man-made harbour and the future site of the world's largest airport, capable of handling 12 million tons of cargo every year. Finally, the sourcing and supply strategy, pre-positioning and stocking mechanisms and additional support requirements and availability of National Society stocks in each region were also taken into account [CGW10].

Since June 2006, the 3 RLUs have been able to deliver mobilisation, procurement, stock, warehousing and fleet services within their respective geographical region. In Geneva, 14

[13] Regional Logistics Units
[14] Pan American Disaster Response Unit

Table 8.1: Criteria used to choose the location of actual warehouses, according to UN reports and websites

Depot location	Criteria used for the choice of location
all	Disaster characteristic data (frequency of occurrence and location)
Brindisi (Italy)	Where drought frequently occurs (Africa) Fixed costs covered by government
Subang (Malaysia)	Strong governmental and commercial commitment Overall quality of human resources Increasingly well developed infrastructure Adequate financing Innovative approach to logistics
Panama	Good infrastructure Excellent communications Availability of clearing and forwarding agents Simple custom procedures Good prospects of obtaining warehousing from government Proximate to the countries most likely to need assistance
Accra (Ghana)	Vicinity of Accra international airport Able to cover west Africa
Dubai	Proximity of Dubai humanitarian city Able to cover east Africa and south Africa

logisticians have assumed the overall management, strategy and funding responsibilities for global logistics activities. Some activities such as medical logistics, logistics tools and standards, global framework agreements and construction contracting also continue to be managed centrally in Geneva.

These choices for location are still under discussion at IFRC. An internal study indicated that "the contingency stock[15] does not have to be located in Kuala Lumpur. There may, in fact, be both economic and logistical advantages to holding stock in Singapore" [Dum06].

This is for the warehouses managed by the federation's RLU, reporting to Geneva. You can also find sub-regional stocks, this time managed by the 7 zones. Here, the head quarters are not responsible for management and location. For 2010 and 2011, the IFRC LRMD[16] has planned to work on a better cooperation with heads of zone in terms of stock management for existing stocks and choice of location for future additional sub-regional warehouses. The main issue is a political one: not all heads of zone are ready to let Geneva "advise" them.

It is also possible to find local stocks held by national societies, but these are, more often than not, a part of RLU stocks and/or managed by RLU when dispatched on the field.

8.2.2 Vehicle stocks

As for vehicles, the timing of decentralisation was more or less identical. Until 2005, a unique global fleet base was available in Dubai. In 2006, they also decentralised their vehicle stock by

[15] stock pre-positioned in warehouses to enable a quick and massive response to disasters
[16] IFRC Logistics and resources management Department

locating 10 to 20 vehicles in each of the 3 RLUS as well as 3 or 4 in some smaller warehouses in Africa.

The decision to decentralise the vehicle stock was obvious for IFRC staff. “We can fly cars from Dubai to anywhere in the world, but the question is cost. How to relocate the stocks to be more efficient in terms of response and costing? How to set up this very initial stock that is required in our disaster response mandate? Where to locate them and how to manage them? That is why we are preparing one central stock which is Dubai. At the same time Dubai will be part of a regional stock, added to Kuala Lumpur and Panama. Because of the nature of disasters, there are very frequent disasters in Africa which are small or mid-size disasters. That is why we have decided to locate sub-regional stocks in Africa. This is just for FACT[17] teams, to be able to operate in the first several crucial weeks of the disaster. These sub-regional stocks will be in Harare, Dakar and Nairobi.” [Zub08]

In terms of cost efficiency, the decision to bring in a dedicated vehicle fleet for each part of the world, where a disaster relief operation takes place may seem inappropriate. Indeed, to ship, or at worst, send a vehicle by plane could easily end up costing as much as buying a brand new vehicle locally could. One alternative solution would then be to buy or rent them wherever a disaster strikes. This is in fact what some UN agencies are already doing; buying old military trucks and Jeeps locally at less than one fourth of their price when they need them, and abandoning them when they leave the operations.[WFP10]

According to IFRC, though, this would not be in line with their safety standards. This is how they explain their choice of maintaining their own vehicle fleet. “If you look at the concept of disaster response, we have to be there within 48 hours. We have to be there at the right time with the right equipment because you don’t have time to waste. What is this car? Is it in good condition? Can we register it? These are all questions which are not allowed in disaster situations. That is why we preposition vehicles, we even pre-prepare them with emergency response capabilities. They have heavy duty bumpers, wind-shields, radios roof racks, registration plates, so when they are loaded onto the plane for disaster zones, they can be right away driven off the plane directly into the operation.” [Zub08]

Figure 8.2 on the next page proposes a summary of the existing pre-positioned resources managed by IFRC headquarters in Geneva.

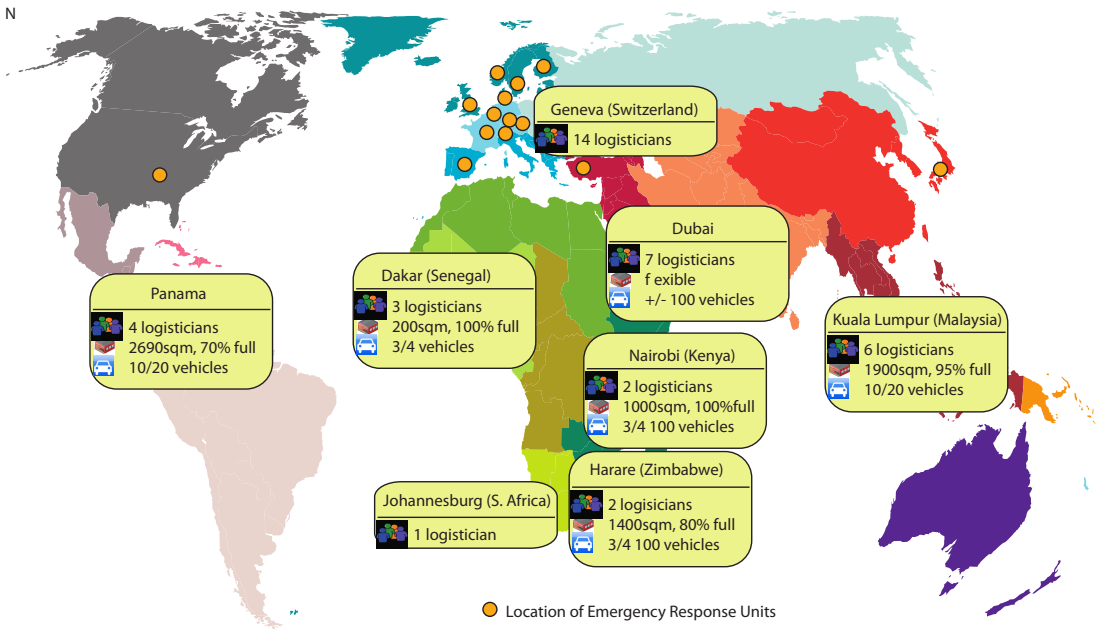
8.2.3 Human resources

In addition to relief items, vehicles and fixed staff, IFRC disaster management is also based on pre-trained teams of experts who can be sent to the field as soon as a disaster occurs. Those ERUs[18] are financed by National Societies (NS). They are usually composed of Red Cross volunteers who have regular work outside the Red Cross movement.

Out of their 35 emergency response teams, 30 are located in Europe, 1 in Japan, 1 in Turkey and 2 in the USA. This is not particularly in line with the localisation of disasters. As a consequence, to enable better communication on the field with locals, in watsan[19] ERU for example, ERU teams usually include two people from the affected country.

[17] Field Assessment and Coordination Team
[18] Emergency Response Units
[19] Team specialized in issues linked with Water and Sanitation

Figure 8.2: Available resources at IFRC in 2008



8.3 Aggregated view of existing pre-positioned resources you can find in various organizations

The two previous sections showed two of the largest existing logistics networks. Other organisations, such as MSF[20] or Oxfam have their own network and logistics strategies. MSF has a fairly centralised network, with a big hub in Bordeaux (France). They have made the decision not to open new warehouses in other parts of the world, but to extend this one to 11000m^3 by 2012. Oxfam, on the other hand, maintains sub-regional stocks were they operate and have mainly local suppliers. [Wor10]

This diversity in network configurations and the choices for location made by various organisations is illustrated by figure 8.3.

8.4 Scope of our study

Pre-positioning vehicles and human resources is slightly different from pre-positioning relief items. For vehicles, it is essential that there are spare parts in the right place, in the right condition and in the right quantities. It is also necessary to have the correct skills in place to plan and do the maintenance. Finally, it would be essential that everything is sent back to the warehouse once operations are closed.

As for Human Resources, relocating actual emergency teams could not be done without much political trouble, as they are usually located in the countries which fund them. Indeed, even though training, kitting out and sending an emergency team to the field is costly, this expertise is recognised and visibly linked with the donating country. This visibility would be much more difficult to achieve if the resources were “foreigners” located in a country close to the disaster.

[20] Medecins sans Frontiere / Doctors without Borders

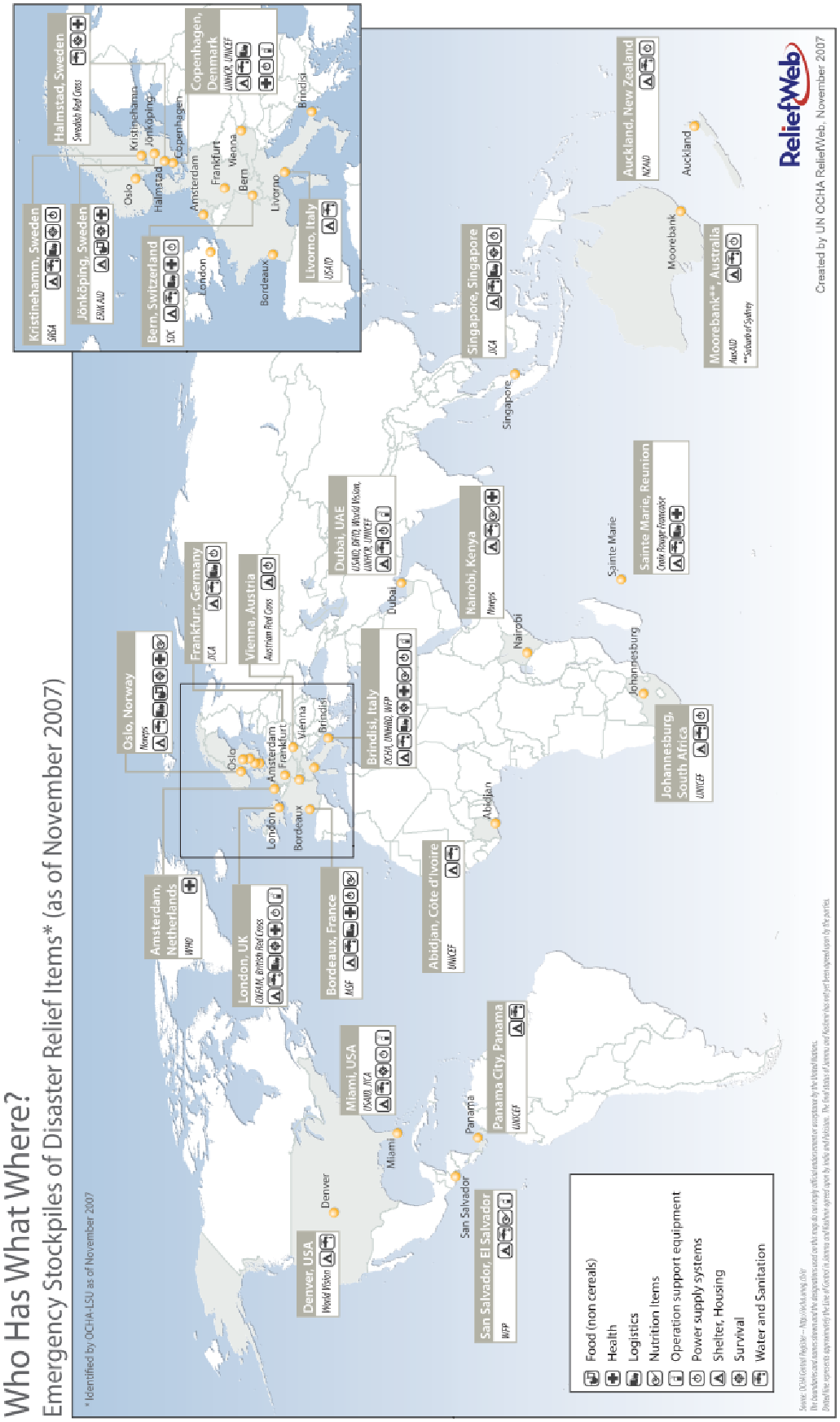


Figure 8.3: Who has What Where

Moreover, according to IFRC [Sec08]; [Jon08], many arguments comfort this course of things. First, ERUs[21] are deployed for big emergencies only, where the main problem is speed, and not cost. Indeed, on these occasions, there is usually a lot of media coverage, which ensures sufficient funding from the beginning. In addition, they already have many existing ERUs and don't intend to increase their numbers. Should they decide that having well positioned teams is worth the extra cost involved in increasing the number of ERUs, then they would also have to accept the inevitable decrease in skill level i.e more teams would mean less deployment for each. Also to be taken into account is that the relocation of existing ERUs is not possible under current conditions, as ERU members usually have regular jobs outside IFRC, MoU[22] with their employers only allowing them to leave their jobs when an emergency strikes, for a few weeks at a time, once or twice a year.

That said, we could still argue that it is possible to pre-position ERU materials, and send only team members upon emergency. This would dramatically reduce the costs as ERU equipment is usually both heavy and fragile, including items such as 4x4s and technical equipment. Yet, ERUs need to train with their material, so it means that they would need two sets of materials. According to them, it is much easier to have everything in one place and send it together rather than have it widespread. Studying the pre-positioning of adequate human resources and means of action with objective tools such as mathematical models would nevertheless be interesting. First, because it is as vital to have available resources to manage the crisis as it is to have adequate relief items to distribute. Secondly, because the design of the network depends on the resources you include in your study. Focusing on relief items without taking into consideration human resources and means of actions makes the analysis incomplete. Yet, due to all the above mentioned elements as well as by the necessity to keep this thesis within an acceptable size, the study of those two elements is considered as future work, outside our scope. We will nevertheless study the sensitivity of the model to the nature and number of items to validate our study.

[21] Emergency Response Units

[22] Means of Understanding, to precise the conditions under which the ERU team member works for IFRC

9

Motivations to decentralize supply chains

As seen in the previous chapter, an increasing number of humanitarian organisations have successfully opened regional warehouses. They are also thinking about or have already started to pre-position resources on a local level. Their choice for location, on both a regional and local level, may be helped by decision-support systems. Our proposition is to use OR[1] to help humanitarians configure their logistics network so that for a given level of service in terms of agility, they improve their efficiency.

The present chapter explains why the problem of warehouse location for humanitarian organisations is important. It gathers arguments from practitioners as well as academics on the need to position humanitarian resources on a local level. It also explains why we choose to build a specific decision-support system.

9.1 Which motivations to pre-position resources on a local level

9.1.1 Main motivations given by IFRC

IFRC[2] Disaster Management's core project for the years to come consists of developing an integrated sub-regional stock strategy, identifying optimal stock locations from where support can be provided and make better use of existing stocks held with other Red Cross / Red Crescent Societies, the ICRC[3] and other partners further increasing our cost effectiveness and efficiency [IFR07a]. This core project has been defined because IFRC is convinced that having sub-regional stocks would enable them to "improve customer services by getting nearer to the field" [Ols07]; [CGW10]

Indeed, it was pointed out that even if RLUs are geographically closer to the regions often struck by disasters, they are still too far away from the local communities with regards to culture, knowledge and geographical distance. Hence, some have pointed out that the RLUs become 'stuck in the middle' – far away from Geneva as well as the local communities. Establishing sub-regional warehouses even closer to the disaster prone areas is being discussed [Jah09].

[1] Operations Research
[2] International Federation of the Red Cross and Red Crescent Societies
[3] International Committee of the Red Cross, dedicated to disaster relief operations in case of conflicts

An overall goal is therefore to shorten the response time, even if it lengthens the preparedness and recovery period [Jah09].

It would also help in terms of visibility. If there is one clear supply chain from supplier to beneficiaries, the complexity of disaster response would decrease dramatically. Having local stocks managed by IFRC would reduce the fact that National Societies sometimes enter the supply chain as parallel systems [Ols07]; [CGW10]. It would therefore improve both visibility and coordination with national societies and other national NGOs.

In terms of knowledge management, there are many advantages to developing local capacity by maintaining local stocks. In the current situation, most of the knowledge is lost once operations are closed. "...we build in such a huge infrastructure – people, capacities – and somehow with the close of the operation, the close of the funding, everything comes down... anything else coming up there, we need to start from scratch... We need to build in some institutional memory, we should have some national staff trained to be able to take over some responsibilities and retain the experiences...."[Jah09]

Having sub-regional stocks would therefore improve knowledge management and reduce the impact of high turnover of human resources.

9.1.2 Motivations given by other agencies

Other organisations usually agree on most of IFRC motivations. Short delivery times, reduced transportation costs and building local capacity are elements, that PAHO[4] it enumerates in its reports for example.

In addition to that, they insist on the fact that, normally, local shipments require less documentation than international consignments. According to them, it also increases the quality and predictability of local purchases and supports the local economy [Org01] and increases local preparedness level (processes, products and partnerships defined) [UNO07], [Org01]

Yet, if many of the advantages in maintaining local stocks are stated, some disadvantages are nevertheless added. According to PAHO[5], local warehouses with local suppliers may be dangerous as items may not always be available in the quantity and quality needed. It can also generate competition between organisations for the purchase of a product and can cause shortages in the local market. Moreover, according to OCHA[6], they should pay attention not to undermine local capacity by developing a parallel network.

To avoid such issues, according to OCHA, humanitarian agencies and their private sector partners should "work together to engage national and local authorities as much as possible in their collaborative efforts if appropriate" and "build local skills and resources ensure that their efforts do not undermine local capacity." They should "work together to develop partnerships that are predictable in nature. To this end, long-term partnerships should ideally be developed in which risk, needs, and support are identified in advance, and all related relationships and processes are defined in advance for effective partnership implementation. Such long-term partnerships will allow both parties to continually learn and thus improve the impact of their relationships on communities affected by humanitarian crises worldwide" [WEFO07].

[4] Pan American Health Organization
[5] Pan American Health Organisation
[6] United Nations Office for the Coordination of Humanitarian Affairs

9.1.3 Motivations found in the literature

In cases such as ours, where products are more or less universal, one can consider either centralised or decentralised systems. According to [SKS03], centralised systems are generally better in terms of safety stock, overhead costs, economies of scale, moreover, they enable the utilisation of risk pooling. Decentralised systems are better in terms of lead time. As for transportation costs... it depends. Upstream/outbound transportation costs are directly related to the number of warehouses used (total distance travelled is greater and quantity discounts are less likely to apply). However, downstream/inbound transportation costs are likely to fall because the warehouses tend to be much closer to the market areas.

In addition to these elements of performance, if we refer to academics, reflecting on supply chain design also pushes companies to reflect on Strategy, Strategic Partnering and Procurement Strategies, which are essential questions. “Rethinking your supply chain strategy not only involves coordinating the different activities in the supply chain, but also deciding what to make internally and what to buy from outside sources." You can also reflect on “what types of partnerships can be implemented, and which type should be implemented for a given situation?” [SKS03].

According to academics, decentralising a logistics network would also decentralise decision making. If we refer to [Sha00], while centralised decision making is needed to realise efficiencies stemming from integration, decentralised decision making is needed for rapid, detailed execution of operations.

Moreover, “centralized systems allow the sharing of information and, more importantly, the utilization of this information in ways that reduce the bullwhip effect and improve forecasts. Finally, they allow the use of coordinated strategies across the entire supply chain – strategies that reduce system-wide costs and improve service level” [SKS03].

When retailers, manufacturers and distributors have different owners and objectives, it is recommend “to form partnerships to approach the advantages of a centralized systems.” [SKS03]

Table 9.1 on the following page summarises all the arguments for and against decentralised supply chains, from the points of view of both practitioners and academics.

9.2 What we can and cannot take into account

According to PAHO[7], some countries have ratified the Convention on the Privileges and Immunities of the United Nations, of 13 February 1946, which includes a series of measures to expedite the inflow and outflow of humanitarian supplies. Multilateral agreements among member states of regional pacts, such as the Central American Common Market or the South American Mercosur, have led to the inclusion, in their customs legislation, of preferential treatment for such supplies [Org01].

Even taking into account such agreements, it is nevertheless essential "to establish contact with the customs authorities to learn their procedures and requirements and, if possible, negotiate special conditions, such as tax exemptions or priority processing of humanitarian supplies” [Org01]. This should be done during the planning phase, and not during the response phase as it is sometimes the case.

[7] Pan American Health Organization

Table 9.1: Advantage and disadvantage of a decentralized supply chain

Source References	IFRC ([CGW10] ; [Jah09] ; [Dum06] ; [Sec08];	Other organizations [WEFO07]; [UNO07];[Org01]; [Wor10] [WFP10]	academics ([SKS03] ; [Sha00] ; [SDR09] ; [Sny06])
Advantages	Reduce lead times	Shorten delivery times	Improve lead times
	Improve knowledge of local culture and specificities	Reduce transportation costs	Increase rapidity and detail of execution of operation
	Enable to start needs assessment in the preparedness phase	Reduce heavy documentation and custom clearance procedures	
	Better prepare local communities	Support local economy	
	Improve visibility	Increase the quality and predictability of local purchase.	
	Improve coordination with national societies / national NGOs	Increase local preparedness level (processes, products and partnerships defined)	Enable internal reflexion about partnering and outsourcing opportunities
	Improve knowledge management and reduce the impact of high turnover of human resources		
Disadvantages	None cited	Pay attention not to undermine local capacity by developing a parallel network	May hinder efficiency, integration and sharing of information
			May increase bullwhip effect
			Increase safety stocks and overhead costs
			Prevent economies of scale and risk pooling

This means that a complete model should include the presence, or not, of international agreements and therefore the level of ease and costs involved in custom clearance. Yet, the choice of location by an optimisation model cannot take political negotiations into account, as we are neither able to gather all existing agreements nor in a position to estimate the opportunity to add more. We have therefore included an index based on the corruption level of local authorities, which was the closest indicator we found to describe the willingness of countries to accept exemption for humanitarian organisations.

For our model to be applicable by humanitarians, we need to take into account some field specificities, like security, corruption, accessibility and telecommunication means. They are detailed in chapter 14 on page 149.

10

Mathematical models as decision-support system

10.1 On the need of a specific decision-support system to optimize the logistic network

Over the last fifteen years, a change towards a recognition of the importance of logistics has been initiated by major organisations such as the IFRC[1] and WFP[2]. Other "organizations in the sector are beginning to follow suit and raise the profile and professionalism of logisticians" [Was06b]

This has lead to the definition of a clear "logistics strategy" for non-profit organisations. Yet, few or no organisations go as far as using optimisation-based decision-support systems. They usually limit their searches for locations to countries where they are already established.

This goes against recommendations found in the academic and business world. According to [SKS03], "a thorough logistics network analysis should consider complex transportation cost structures, warehouse sizes, manufacturing limitations, inventory turnover ratios, inventory costs, and service levels. These issues require the use of optimization-based decision-support systems that can solve large-scale problems efficiently."

Moreover, having such a system would help in terms of impartiality. "Responses to recent disasters continue to raise issues around the impartiality of humanitarian assistance. Observing the humanitarian principle of impartiality means that assistance should be given according to, and be in proportion to, need alone. International humanitarian financing is currently far from realising the principle of impartiality. The National Audit Office showed in 2003 [DFI03] that DFID[3] had calculated that, since 1997, the per capita level of humanitarian assistance it had provided in European emergencies had been five times higher than for emergencies in Africa. The report concluded that it was possible that the discrepancy in resource allocation was partly attributable to wider strategic considerations" .. source : [DFI03] ref : [Gro06]

[1] International Federation of the Red Cross and Red Crescent Societies
[2] World Food Program
[3] Department For International Development (DFID) is a United Kingdom government department

Table 10.1: Litterature Review

key words	ISI web	Science Direct	informs	MSOM	MS	OR	POM
"facility location" and "disaster" in topic	24	14					
Various combinations of "facility location" "disaster" 'emergency" "humanitarian" "supply chain design"			6	1	2	4	1

Humanitarians have also come under increasing pressure to prove to donors, pledging millions in aid and goods, that they are reaching those in need. This means they must be more result-oriented as they become more accountable and therefore their operations must be more transparent [Was06b].

Finally, using OR[4] would help to manage the complexity of the problem and to increase objectivity and impartiality of the decision.

10.2 Existing studies in literature

Table 10.1 summarises the existing articles related to facility location to respond to disaster. As the total number of articles is too big to provide a detailed analysis of them all, we will restrict this literature review to the papers and thesis that are either relevant to our study or representative of existing works ([HM05]; [OEK04]; [AB06]; [Sal10];[Bal08]).

Most of those papers tackle the problem of resources during the response phase, but not during the preparedness phase. The articles, that take a preparedness point of view, have one or more of the following particularities:

1. They use only data from past disasters to choose the locations, without considering the evolution in nature and number of these disasters (they use all past disasters, even those which happened 100 years ago)
2. They focus on effectiveness maximisation (max coverage)
3. They propose models that can only be implemented on a local point of view.
4. They are too far away from field realities, as they do not take into consideration local parameters such as security, corruption, accessibility or available telecommunication means.
5. They focus on relief items pre-positioning and neither validate the sensitivity of their model to the nature and number of products, nor consider other resources like human resources and means of action such as vehicles.

Our aim is both to complement those studies and to take into account the specifications asked by all the humanitarian practitioners that we interviewed. To this end, first, we will propose

[4] Operations Research

a study of humanitarian demand, its recent trends and influencing factors. This better fits with strategic decisions, where outdated data should not be considered. Secondly, we will not maximise effectiveness, as interviewees, especially at IFRC, insisted that the problem is not to maximise the coverage because plane deliveries allow them to cover wide distances quickly. According to them, the idea is more about how to achieve a given level of effectiveness in the most efficient way. In other words, they would prefer to minimise the costs to meet the demand in specific time-frames, which is what we propose. Thirdly, we optimise the design of the global network, taking into account many crises in many parts of the world. We will focus neither on the management of the network nor on local last mile delivery. We will nevertheless include some local considerations; to choose the best country once we define which parts of the world should host a warehouse. Finally, although this thesis only takes into account relief items, we also analyse the sensitivity of the model to the nature and number of products considered.

10.3 In our case, how to model the problem ?

10.3.1 Deterministic or Stochastic programming

The usual method of dealing with demand uncertainty is to use a stochastic or robust optimisation model (see table 10.2). Yet, if we refer to [SDR09], the stochastic optimisation model optimises the random outcome on average. "This is justified when the Law of Large Numbers can be invoked and we are interested in the long-term performance, irrespective of the fluctuations of specific outcome realizations." In our case, the impact of those "fluctuations" are on human lives and can be devastating. We therefore aligned with the recommendation provided by [Sha00], which is to construct multiple scenarios of an uncertain future and optimise a linear programming model for each scenario. Indeed, "deterministic optimization of a model of a supply chain planning problem is often the most practical approach. In most planning situations, the development of points (that is, single) estimates of key parameters is difficult enough. For such problems, it is not realistic to attempt to develop extensive descriptions of how the parameters might vary in the future. Although the modeller may sometimes be forced to acknowledge that a deterministic model is imperfect in its description of the future, the benefits of using such a model are still substantial."

This choice to use a mixed-integer linear program also enables us to take into account the IFRC requirement on service level. These constraints to send relief items for 5000 families within 5 days after the crisis, 15000 families 15 days after the crisis, and the overall demand after 2 months induce a dependence over time, which is not easy to model with a stochastic approach.

We use a scenario approach, as it results in more tractable models. It also allows the parameters to be statistically dependent and thus enabling to model reality, where parameters are usually dependants and therefore difficult to model. For example, demands are often correlated across time periods or geographical regions and costs are often correlated among suppliers [Sny06].

Next chapter (ch. 11 on page 103) provides elements to better understand humanitarian demand and explains how we have used those elements to build our scenarios.

10.4 Overview - What are we doing exactly?

Our model aims at answering questions that many humanitarian organisations have been asking themselves recently:

- How many warehouses should we open?
- What is the optimal size of warehouses?
- Where should we position resources to enable a quick and adequate answer to disaster?
- Shall we keep existing warehouses or relocate them?

To answer these questions, we have developed a mixed-integer linear programme. Its inputs are as follow:

- The "demand", established using a list of past crises, represents an estimated demand per person in disaster cases and the probabilities of such disasters evolving. We also impose a given level of service, reflecting the numbers rescued and delays in response-time. (see section 11.4)
- Costs and delays relating to the purchase of items, running warehouses, delivering items from suppliers to warehouses, and from warehouses to beneficiaries, by air and by sea. (see section 12.2)
- The actual locations of suppliers. (see section 12.4)

This last point can, and should, be modified, partly because supply is uncertain in the context of humanitarian aid (see part 1), and also because local warehouses are opened and operated by humanitarian organisations to build local capacity, which in turn contributes to strengthening the local supply network.

Various simulations have therefore been run to examine how the availability of local suppliers changes the outcome of our study. We also compare two further possibilities; the simple,

Table 10.2: deterministic or stochastic approach ?

Situation	Problem known as		Goal
Certainty	deterministic optimization problems		
Risk (uncertain parameters, but values known by probability distribution)	stochastic optimisation problems	optimize the expected value of some objective function	"Find a solution that will perform well under any possible realization of the random parameters" "choosing an appropriate performance measure is part of the modelling process"
uncertainty (no information about probabilities is known)	robust optimization problems	(often) optimize the worst case performance of the system	

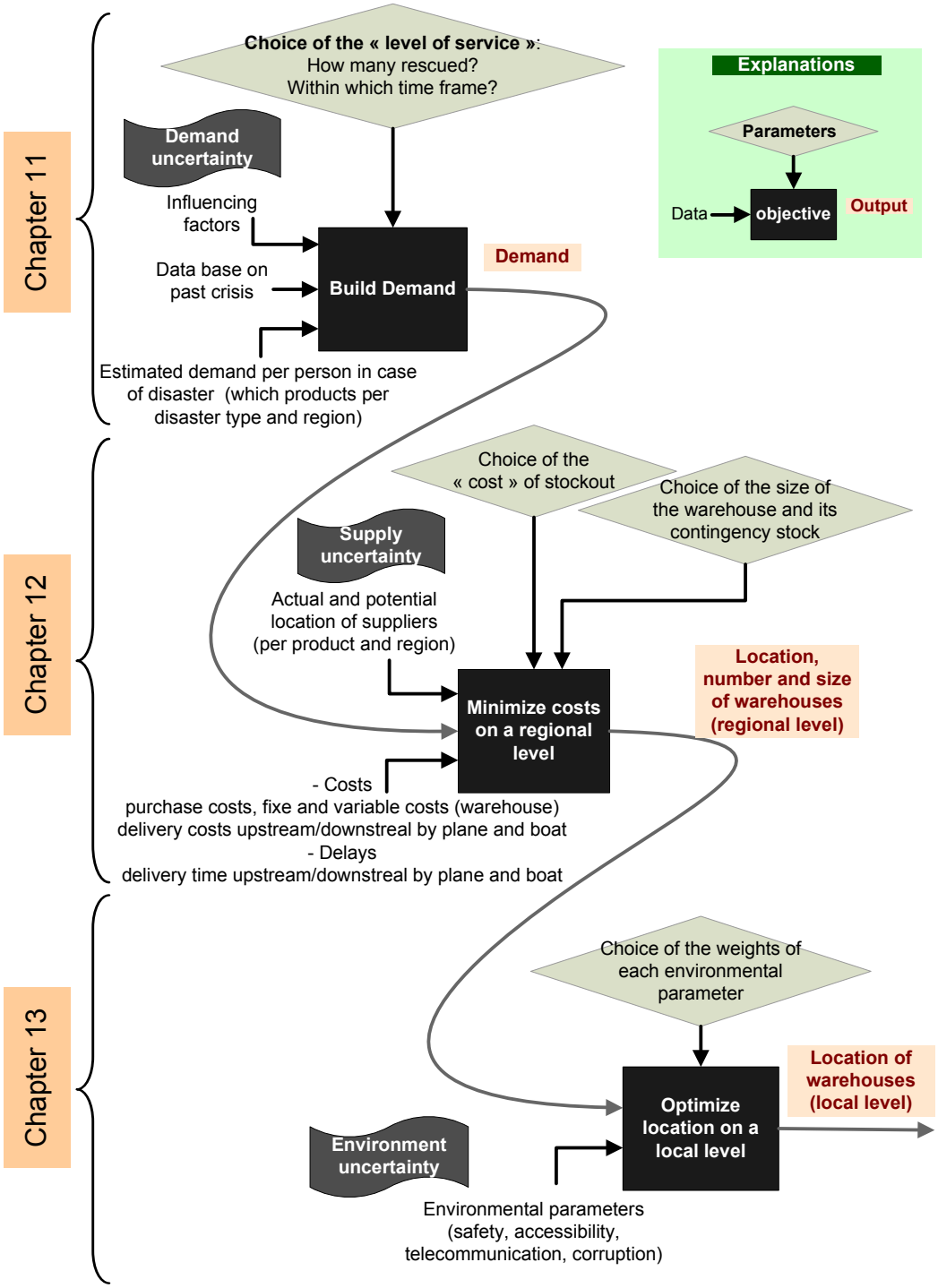
one-stage logistic network, as exists nowadays in most organisations, compared to a two-stage logistic network.

This model gives optimal locations on a regional basis. The final choice of the country in which a warehouse should be built is carried out by a separate analysis (see figure 10.1). Indeed, for this specific choice, local parameters do exert influence; local customs procedures, safety and security, accessibility and telecommunication networks, are all significant small-scale elements. It would not have been relevant, however, to incorporate them in our regional cost-optimisation model, as regions are sometimes comprised of countries with highly diverse profiles.

At a regional level, chapter 12 on page 113 details all of the hypotheses employed to build the MIP[5], and explains the model itself. Chapter 13 provides the results and sensitivity analysis. Chapter 14 on page 149 will then summarise this approach and provide results for the choice of specific locations within the identified optimal regions.

[5] Mixed-Integer Program

Figure 10.1: Overview - What are we doing exactly?



11

What is the demand?

11.1 What is the demand? How to model it? General thoughts

If we refer to [SKS03], decisions made at the strategic level, which include distribution network design, have long-lasting effects. This implies that changes in customer demand over the next few years should be taken into account when designing a network. This chapter explains the nature of humanitarian demand, how it has evolved over the last decade, and how it is expected to evolve in the future. This will serve as a basis upon which to build the scenarios examined by this study.

Uncertainty of demand is an issue that is common to many supply chains. In the case of humanitarian organisations, this uncertainty is reaching a climax. "Natural disaster risk assessment is a typical issue with imprecision, uncertainty and partial truth. The two basic forms of uncertainty related to natural disaster risk assessment are randomness caused by inherent stochastic variability and fuzziness due to macroscopic grad and incomplete knowledge sample" [HS02].

Nevertheless, according to the current thinking, disaster trends are changing. If we refer to ([EM-];[IFR07b];[IPC07]), disasters should be more numerous but of smaller scale in the future. Added to this is urbanisation, which further alters the impacts of disasters. Studies of the potential impacts of climate change also predict developments in the types of disaster recorded, their locations, and their intensities. Section 11.2 will analyse data from past disasters to measure these parameters. It will also provide valuable information regarding seasonality, in order to design an adaptable network that can anticipate decisions concerning inventory management. Section 11.3 will then summarise the literature to list the various factors that may influence future humanitarian demand. Finally, section 11.4 will explain how these elements have been included in the simulations.

11.2 Past disasters and trends

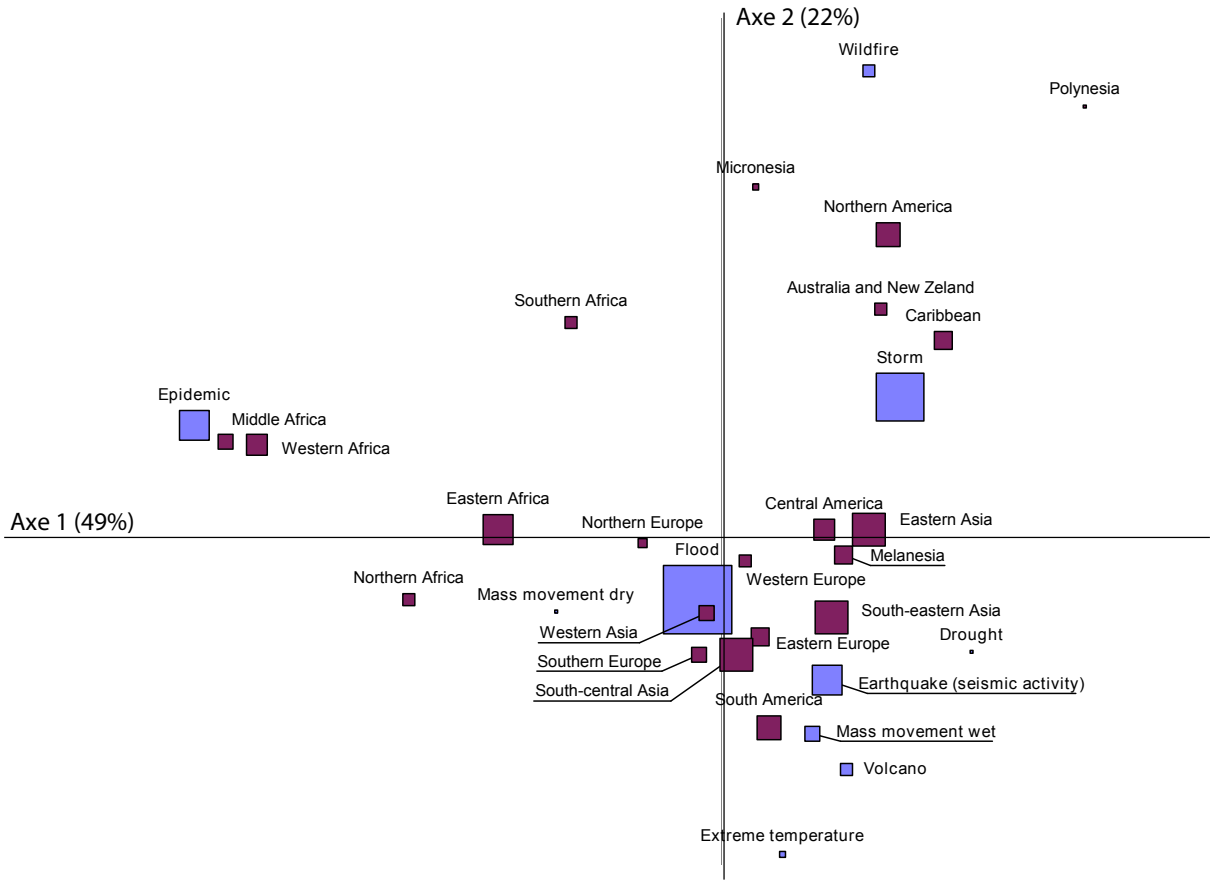
The imprecision of the data regarding delivery costs and times, and the size of the model, mean that it is unable to optimise locations on a small scale. For the purposes of this study, the

world has been sub-divided into 21 regions (see previous chapter), consisting of groupings of countries that are geographically close. These regions constitute the "customers", or potential beneficiaries. In order to better define the nature and quantity of items that are potentially required in those regions, data from past disasters has been analysed. Figure 11.1 provides a factorial analysis of the correspondences that exist between regions and disaster types.

11.2.1 Profile of regions

As can be seen in figure 11.1, regions exhibiting similar disaster types are geographically close. African countries are more subject to epidemics, whereas in Asia there is a greater risk of being affected by earthquakes of floods. Australia, New Zealand, the Caribbean and North America are most affected by storms.

Figure 11.1: Cluster of regions



Region / Type	Australia and New Zealand	Caribbean	Central America	Eastern Africa	Eastern Asia	Eastern Europe	Melanesia
Drought	1	1	1	1	13	1	
Earthquake (seismic activity)	4	3	1	8	28	2	
Epidemic	4	7	5	63	19	10	
Extreme temperature	1	1	1	2	1	12	
Flood	1	6	1	4	12	9	
Industrial Accident	2	3	4	4	46	1	
Mass movement dry	1	1	1	1	3	1	
Mass movement wet	2	1	3	2	1	2	
Miscellaneous accident	3	4	1	1	4	7	
Storm	9	82	8	11	17	7	
Transport Accident	1	2	3	3	3	1	
Volcano	1	1	2	1	3	2	1
Wildfire	15	2	1	3	1	1	
TOTAL	**43**	**103**	**148**	**265**	**350**	**118**	**10**

La dépendance est très significative. chi2 = 1401,50, ddl
Les cases encadrées en bleu (rose) sont celles pour lesqu
Attention, 173 (63.4%) cases ont un effectif théorique in
Les valeurs du tableau sont les contributions de chaque c

This analysis confirms the relevance of a geographical pooling of countries, in order to reduce the size of the model. Furthermore, the analysis provides information regarding the nature of the products that should be stored at the various warehouses, pertinent to their locations. Medical treatments created in response to epidemics, for example, could be maintained in Africa when safety, financial corruption and climatic conditions allow. Similarly, South-Central Asia, which is often subject to floods and earthquakes, should host a warehouse with resources more suited to enabling a rapid response to these kinds of disasters, such as tents and shelter kits.

11.2.2 Seasonality

A rapid, adequate, humanitarian response also demands that relevant items should be sent into the field in appropriate quantities within a reasonable time-frame. Having resources pre-positioned to facilitate rapid disaster-response is a first step. The second step is to ensure that sufficient capacity exists to respond to another crisis if it occurs soon afterwards.

Studying the seasonality of disasters provides an indication of the periods when high contingency stock is crucial, as many disasters may occur at the same time.

Figure 11.2 on the next page illustrates the increased seasonality of disasters. Whereas numbers previously affected were roughly constant throughout the year, they now seem highly seasonal, with June becoming a particularly busy period.

Nevertheless, this apparent trend of increasing seasonality in the occurrence of disasters is open to discussion. Indeed, the present, detailed study of the disaster database indicates that, on average, 5% of disasters affect 90% of the total number of people who are affected by disasters each year. This is in line with the recent assertions of other analysts. "The time trends for the human and economic impact of natural disasters are highly influenced by the occurrence of “mega-disasters” affecting tens of millions of people and/or causing billion of dollars worth of economic damage. These exceptional events lead to a high variation from one year to the next in the disaster impact figures. This great variability makes it difficult to identify clear trends in the human and economic impacts of disasters over time." [Sch+08].

Even so, this heterogeneous situation, comprised of many small disasters in combination with some really big disasters and comparatively few medium-size disasters, is changing. A trend toward more frequent medium-size disasters affecting between 10,000 and 1,000,000 people is clearly visible. This trend is illustrated in figure 11.3, showing disasters of the past decade compared against figures from earlier disasters. This trend is often cited by humanitarian organisations as the key element that has made them realize their logistics network should be re-thought, to ensure that they can respond to such medium-sized disasters in the future.

11.2.3 Disaster intensity, types and location

Figures of past disasters show that the overall number of disasters per year is unchanged over the last decade, as are the total numbers affected. Looking in more detail at these figures and distinguishing the numbers and impacts on the basis of disaster type, it is clear that floods and storms are definitely the most frequent disasters, and the deadliest. This predominance of hydrological disaster is true for small and medium disasters, (affecting less than 1, 000, 000 people), more than for large ones. The trend illustrated in figure 11.4 on page 107 indicates that the increase in medium-size disasters is especially evident in the number of floods.

Figure 11.2: Seasonality

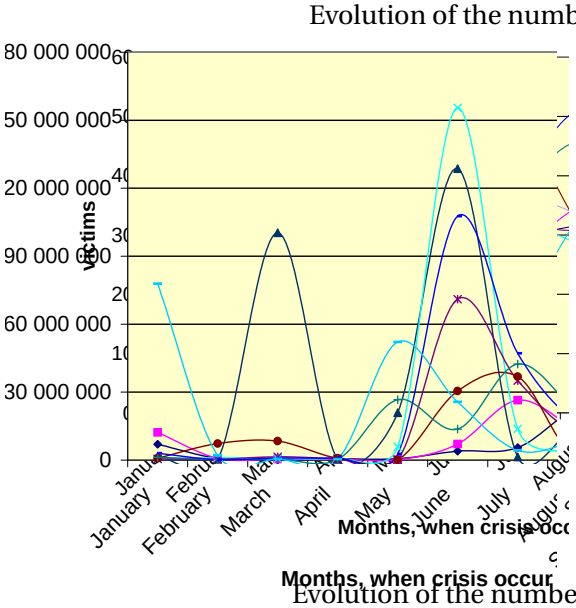
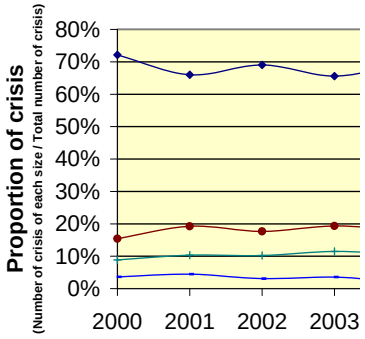


Figure 11.3: Evolution of the number of crisis per disaster sizes



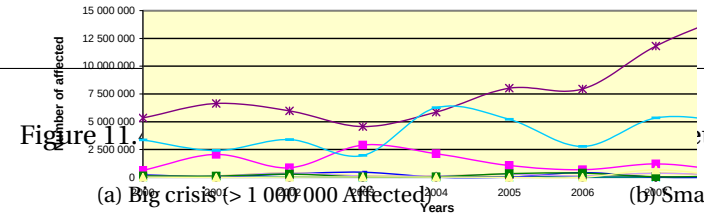


Figure 11. tween big and small disasters

(a) Big crisis (> 1 000 000 Affected) (b) Small crisis (< 1 000 000 Affected)

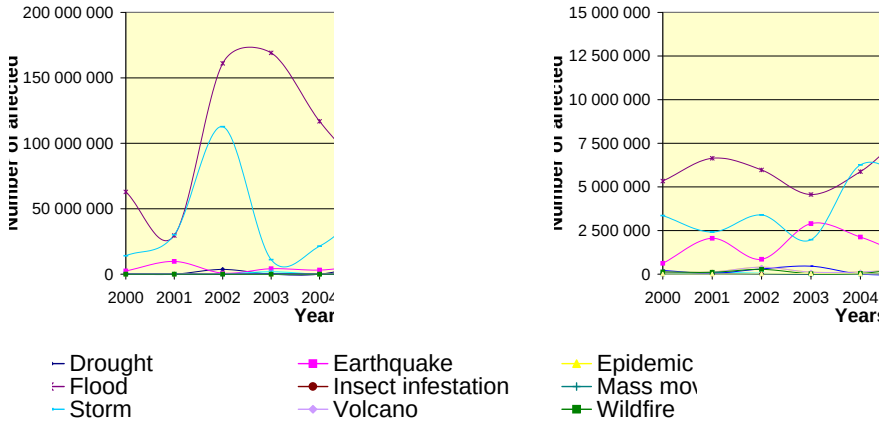
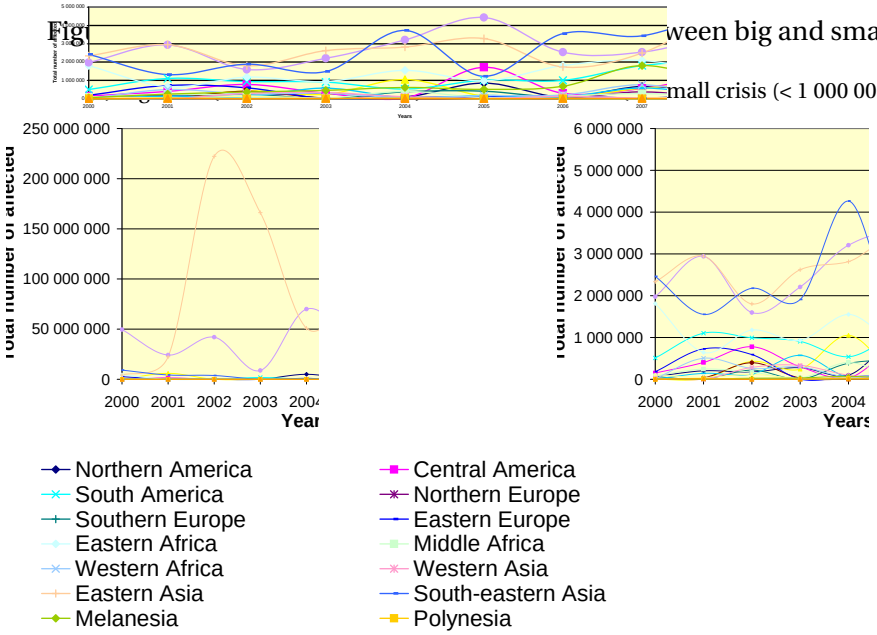


Fig ween big and small disasters

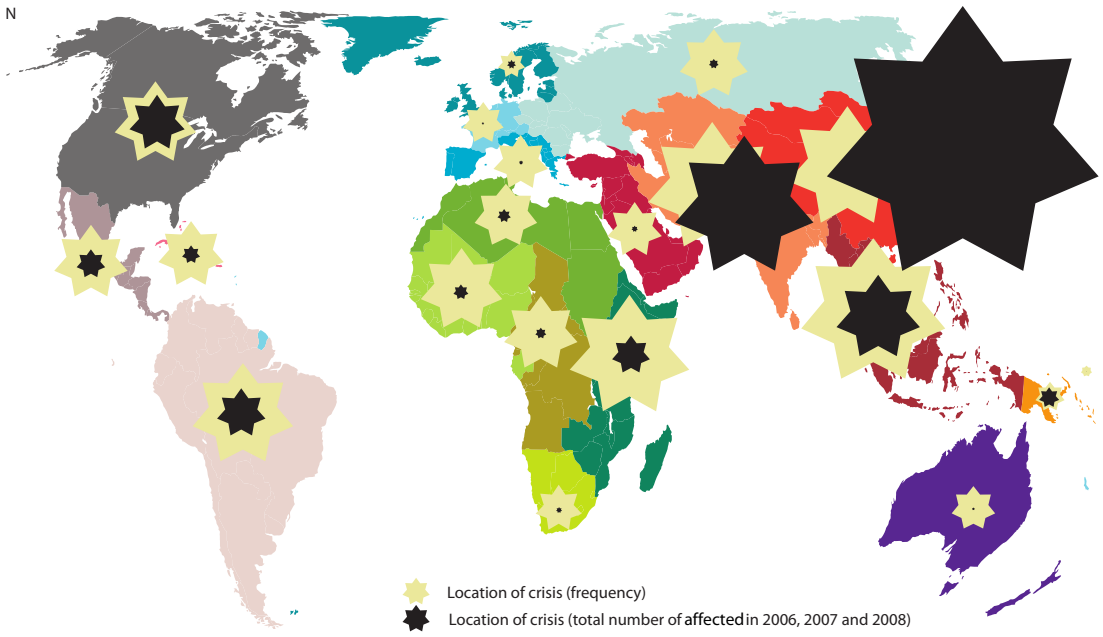
mall crisis (< 1 000 000 Affected)



Turning now to examine the regions in which disasters strike, while South-Eastern Asia is increasingly prone to both large and small disasters, other parts of Asia, from South-Central Asia to Eastern Asia, are increasingly affected by small and medium-sized disasters. (see figure 11.5). Having said this, it must also be underlined that - in terms of total numbers of crises - the geographical location of disasters has remained roughly constant over the years. (Previous analyses were based on the numbers of individuals affected).

Figure 11.6 provides information on the number of crises and their impacts per region, but provides a map representation in order to better understand their geographical distribution. The higher vulnerability of Asian regions for example, becomes obvious. It is also evident that many regions are affected by a high number of crises, even though the number of individuals affected by these crises remains quite low. Consequently, a model that focuses only on the numbers affected, without taking disaster-frequency into account, would completely overlook

Figure 11.6: Geographical repartition of crisis



western Africa or the Caribbean, for example.

In view of these considerations, the optimisation model has been built in a way that takes into account both the impact and the frequency of disasters. (see section 11.4 on page 111)

11.3 Influencing factors

The previous section has provided a rough analysis of the data available on past disasters, but many studies have shown that various factors can influence the observed trends. A review of past disasters is thus necessary, but on its own , it is insufficient for optimising stock locations. This section will analyse the available literature regarding factors that are considered likely to become highly influential on demand in the future. These factors include social and economic vulnerabilities, urbanisation rates and climate change.

11.3.1 Country vulnerability

A huge study on this specific subject was funded by the UNDP[1] in 2004. One of its results is a list of the factors influencing disaster impact (see figure 11.7 on the facing page)

11.3.2 Urbanization

Reports from many organisations underline the dangers linked to urbanisation. According to the UNDP[2] itself, the growth of informal settlements and inner city slums, whether fuelled by

[1] United Nations Development Programme
[2] United Nations Development Programme

Figure 11.7: Estimating the vulnerability of countries, from [Pro04]

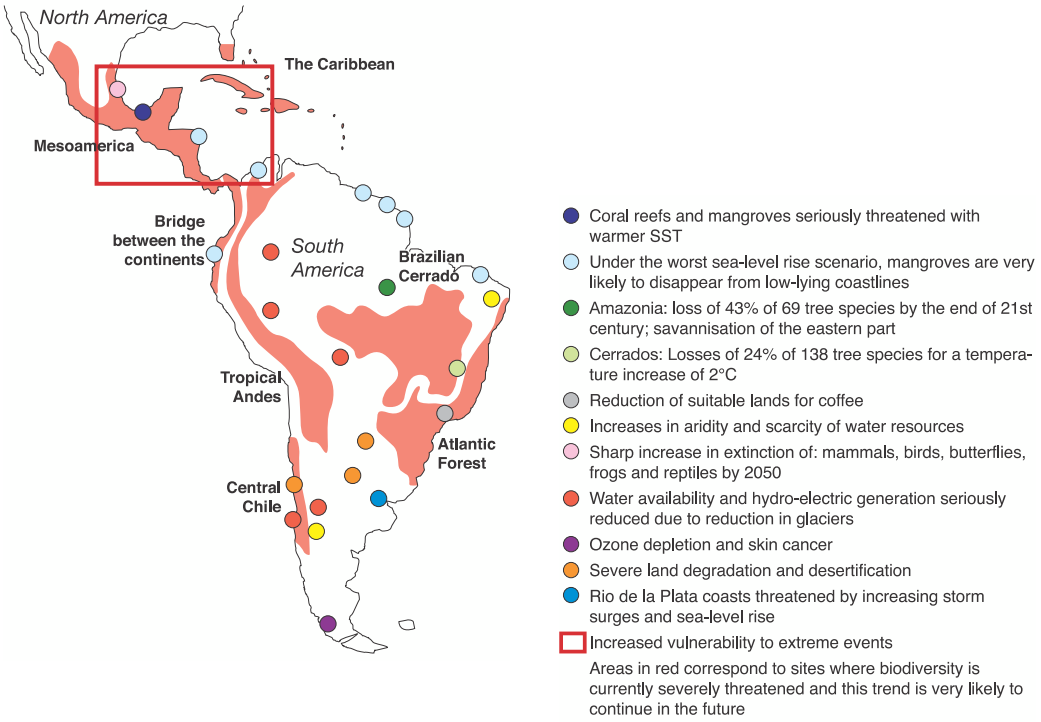
TABLE T.2 VULNERABILITY INDICATORS

Categories of Vulnerability	Indicators	Drought	Flood Earthquakes Cyclones	Source[c]
Economic	Gross Domestic Product per inhabitant at purchasing power parity	X	X	WB
	Human Poverty Index (HPI)	X		UNDP
	Total debt service (% of the exports of goods and services)		X	WB
	Inflation, food prices (annual %)		X	WB
	Unemployment, total (% of total labour force)		X	ILO
Type of economic activities	Arable land (in thousand hectares)		X	FAO
	% of arable land and permanent crops		X	FAO
	% of urban population		X	UNPOP
	% of agriculture's dependency for GDP	X		WB
	% of labour force in agricultural sector	X		FAO
Dependency and quality of the environment	Forests and woodland (in % of land area)		X	FAO
	Human-Induced Soil Degradation (GLASOD)	X	X	FAO/UNEP
Demography	Population growth		X	UNDESA
	Urban growth		X	GRID[d]
	Population density		X	GRID[e]
	Age dependency ratio		X	WB
Health and sanitation	% of people with access to improved water supply (total, urban, rural)	XXX		WHO/UNICEF
	Number of physicians (per 1,000 inhabitants)		X	WB
	Number of hospital beds		X	WB
	Life expectancy at birth for both sexes		X	UNDESA
	Under-five-years-old mortality rate	X		UNDESA
Early warning capacity	Number of radios (per 1,000 inhabitants)		X	WB
Education	Illiteracy rate		X	WB
Development	Human Development Index (HDI)	X	X	UNDP

Source: UNDP/UNEP

c. FAOSTAT, the database of the Food and Agriculture Organisation (FAO); GRID, the Global Resource Information Database of UNEP; WB, World Development Indicators of the World Bank; Human Development Report of UNDP; ILO, International Labour Office; UNDESA, the UN Dept. of Economic and Social Affairs/Population Division. Most of the data were reprocessed by the UNEP Global Environment Outlook Team. Figures are available at the GEO Data Portal (UNEP), http://geodata.grid.unep.ch
d. Calculated from UN Dept. of Economic and Social Affairs data.
e. Calculated from UNEP/GRID spatial modelling based on CIESIN population data.

Figure 11.8: Key hotspots for Latin America, from [Mag+07]; [IPC07]



international migration or internal migration from smaller urban settlements or the countryside, has led to the growth of unstable living environments. These settlements are often located in ravines, on steep slopes, along flood plains or adjacent to noxious or dangerous industrial or transport facilities." This rush for growth can trigger haphazard urban development that increases the risks of large-scale fatalities during such a disaster. For example, once again according to UNDP, the earthquakes that occurred in the Alto Mayo, Peru in 1990 and 1991, at Limon, Costa Rica in 1991 and in the Atrato Medio, Colombia in 1992, exposed new patterns of risk through urbanisation in regions that had a prior history of seismic activity, but which had never previously experienced earthquake disasters of this type [Pro04].

11.3.3 Climate change

In 2007, the IPCC[3] published a number of reports on climate change and its predicted future impacts. Global reports as well as detailed national and regional assessments were provided.

Figure 11.8 presents their conclusions for Central and South America. The IPCC reports also provide additional, detailed figures and maps. Table 11.1 summarises global trends. According to these reports, there is a high probability that we will be confronted with major changes in future humanitarian demand. Heavy precipitations are expected to occur more frequently, for example, which will correspondingly increase the risk of disastrous floods.

While the reality of global warming may still be a subject of debate among some people, humanitarians are willing to prepare for any scenario. For them, "the main question is not if

[3] Intergovernmental Panel on Climate Change (IPCC)

Table 11.1: Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century using the IPCC Special Report on Emission

Phenomenona and direction of trend	Likelihood of future trends based on projections for 21st century
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain (>99% probability of occurrence)
Warm spells/heat waves. Frequency increases over most land areas	Very likely (90 to 99% probability)
Heavy precipitation events. Frequency increases over most areas	Very likely (90 to 99% probability)
Area affected by drought increases (Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period)	Likely (66 to 90% probability)
Intense tropical cyclone activity increases	Likely (66 to 90% probability)
Increased incidence of extreme high sea level (excludes tsunamis)	Likely (66 to 90% probability)

but how to address the risks of climate change. While some impacts can already be seen, or projected fairly accurately, many others will appear as surprises, or only become apparent once climate change progresses. Climate change thus not only raises the risks but also increases the uncertainties" [IFR07b].

As for its impact upon humanitarian demand, for example, "deforestation may increase flood and landslide hazard in some contexts and destruction of coastal mangroves may increase cyclone hazard. Changing natural hazard risks related to climate change will alter disaster risk patterns. Of hydro-meteorological hazards potentially affected by climate change, floods, storms and droughts present the most widespread direct risk to human assets. Flooding and landslides, pushed by heavier rainfall, and by surging sea levels in coastal areas, may become increasingly common. Hazard events such as flooding or temperature increase in highland areas can extend the range of vector-born diseases such as malaria" [Pro04].

11.4 Building the estimations to be used as entry data for our optimization model

Future humanitarian demand, though highly uncertain, can be predicted. Trends highlighted by data of past disasters, combined with known influencing factors, provide a fairly complete vision of potential future disasters, but it is difficult to incorporate this information within a quantitative model. "In fact, the probabilistic method effectively ignores fuzziness of risk assessment with incomplete data sets. As a result, it is impossible to accurately estimate the risks of natural disasters within a specified error range" [ZH05].

The previous sections have clearly shown, however, that "influencing factors" - such as global warming - should not impact significantly upon short or middle-term perspectives. As an example, results of IPCC studies are given for the second half of the 21st-century. It has also

been shown that disaster types and locations, the two most important considerations when establishing warehouse locations, have not changed significantly over the past decade.

The data recorded from recent, past disasters was therefore chosen for a first analysis. The most crucial information on which our model is based is a list of the past 300 to 1000 disasters, (the number being dependent upon the parameter analysed). These lists include the disaster types, their locations, and the numbers of individuals affected in each case.

In order to use this data for providing numerical inputs, three time-frames were defined for the optimisation, with a specific number of rescued individuals set as the target for each of the time-frames. For example, following IFRC's specifications, for a disaster affecting a population of 200,000 people, the network should be able to provide assistance to 25,000 persons within 5 days, 75,000 persons within 15 days and the totality of the victims within 2 months. Other organisations have similar requirements; the WVI for example sends items to "sustain up to 2,000 people for seven days. The second phase involves sending family survival kits, which can support up to 5,000 people for 30 days" [KS07].

If two crises happen within the same time-frame, even if they are not in the same region, then the model aggregates the demands of each crisis. This consolidated matrix of demand is then used as input to find the best warehouse locations. Results will subsequently be discussed and validated over a longer period, by comparing network design and costs - based on actual demand - to costs of a demand modified according to these factors.

12

Our optimization model - Hypothesis, Notations and Model

Humanitarian organisations have to respond to natural crises by sending assistance very quickly as soon as a disaster occurs, usually by providing shelter, medical aid and/or food to victims. In order to improve their responsiveness immediately following a disaster, many improvements need to be made during the preparatory phase, i.e. before the disaster occurs. Working on the configuration of such humanitarian logistics networks helps improve aid effectiveness by creating better-prepared humanitarian organisations.

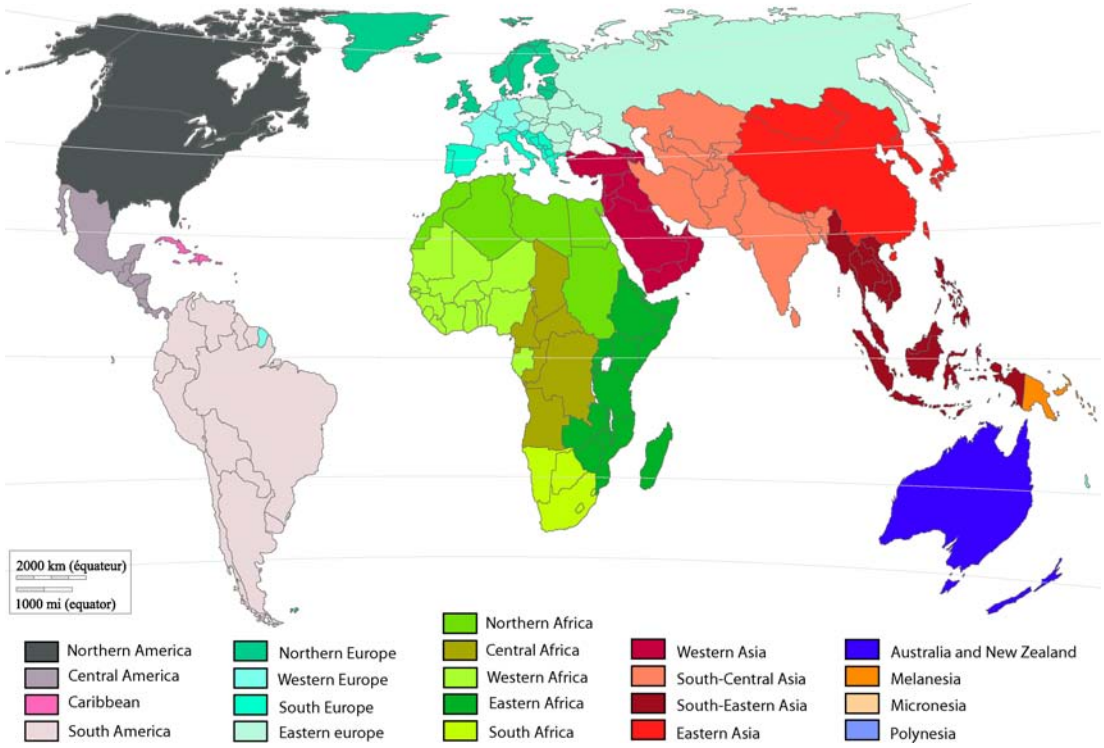
A swift response-time is of course vital for victims, but it is also essential for the organisations' media image. Advanced stockpiling of a variety of resources is therefore crucial for a fast and adequate response. The aim of this study is to identify how the logistics network of a humanitarian organisation might best be configured. Both the location and the size of warehouses will be studied.

The hypothesis on which our model is based has been defined according to information provided by the IFRC. The objective is to satisfy, at the lowest possible cost, the whole of the demand within given delays. In other words, the aim of the study is to help humanitarians configure their logistics networks so that for a given level of service - in terms of responsiveness and effectiveness - they improve their efficiency. In addition to this objective of cost minimisation, other criteria have an influence on the choice of locations that are selected for warehouses. Some, for example, will be preferred for practical reasons, such as security, accessibility, corruption-risk and the presence of telecommunications infrastructures. It is also important to take into account any existing warehouses, to determine whether they should be maintained or relocated.

This chapter will explain the hypotheses that were used to create the model. It will therefore make explicit the constraints and objectives that were employed to design the best logistics network for the highly uncertain conditions in which humanitarians work.

Some explanation is necessary regarding how limits were imposed upon the numbers of affected individuals to be rescued within given time frames. Populations affected by an epidemic in West Africa and a storm in North America will not need the same products. It is therefore necessary to explain how the disaster type - and its location - will impact upon

Figure 12.1: Map of Regions



the types of aid product that must be delivered in response. Further detail will then follow regarding the character and location of the suppliers of such products, and examining how the number, size and location of warehouses are chosen.

12.1 End users and Products

We have chosen the Em-dat regional definition; 21 regions distributed as shown in Fig 12.1.

The network should be able to send given quantities of a variety of products to a region affected by a disaster. To judge whether aid is sent quickly enough after a disaster, a number of targets has been imposed in order to estimate the numbers rescued within different time frames. Such targets are used by many humanitarian organisations, from the IFRC to the WVI. According to the IFRC, their targeted level of service is to rescue 25,000 individuals within 5 days, 75,000 individuals within 15 days, and the total number affected within 2 months.

Of course, for disasters involving fewer than 75,000 individuals, the total affected population should be rescued within 15 days, or within 5 days in cases where less than 25,000 individuals are affected. These values have been employed to study the IFRC network, and have been altered to gauge their impact upon operations costs, warehouse locations and network size. The parameters employed are as described in table 12.1.

As explained in the previous chapter, the demand base is built on the number, type, location and impact of the disasters that occurred during the past 3 years. In cases where two or more disasters occur on the same day, the model aggregates the individual events within the same scenario, in order to provide the best number and locations of warehouses necessary for responding to all of these disasters. From January 2006 to December 2008, 1062 natural crises

Table 12.1: Parameters to build the estimation of demand per product

Notation	Definition	Value for IFRC
NbRescuedAtTime1	Targeted number of people to rescue before Time1	5000 families or 25000 affected
Time1	Time allotted to set up operations and rescue a given number of affected (NbRescuedAtTime1)	5days
NbRescuedAtTime2	Targeted number of people to rescue before Time2	25000 families or 75000 affected
Time2	Time allotted to set up operations and rescue a given number of affected (NbRescuedAtTime2)	15days
NbAff	Total number of affected by the disaster, but also the targeted number of rescued before Time3	
Time 3	Time allotted to rescue the total number of people affected by the disaster	2months
nbT	Duration of operations. nbT>Time3 to allow replenishment of contingency stock and possibility of late delivery.	

affecting more than 100 people occurred, with 1 to 26 disasters occurring during the same day. After this first aggregation, we therefore had 557 scenarios for our detailed studies.

Two additional sets of data are then used to validate the robustness of the resulting proposal from a longer-term perspective. For this reason, the database of past disasters has been modified to take into account foreseeable changes that can be predicted by observed trends. (see section 13.5).

For each of the 557 scenarios of the initial data base, as well as for the modified scenarios, a demand D_{pct} is built to give, for each product, region and time, the number of items that should be sent to affected regions within the various time frames. Algorithm 1 explains how to build D_{pct} for crises starting at a given date t0. The demand is indicated for each day, starting at t0 and finishing at t0 + nbT, where nbT is the total duration of relief operations.

Those crises that occur between t0 + 1 and t0 + nbT have not been incorporated. This was firstly because it was hoped that the model could consider both short and long-term demand, in response to one or more crises occurring simultaneously. Long term projection becomes more difficult if demand changes every morning. Secondly, as a disaster by - definition -cannot be accurately foreseen, the model should not be able to plan deliveries for a crisis that is supposed to occur unexpectedly. Furthermore, no single organisation will respond to every crisis, so that if one aid provider is already involved in operations when a new crisis occurs, other organisations can step in.

Let us consider the demand in kitchen kits, for example. One kitchen Set in dimensioned for a family of 5 persons. If we follow IFRC specifications, for an earthquake in South-Central Asia (c=14), the demand in kitchen kits (p=7) will be :

$$D[7][14][t] = \Big[\ 0 \quad 0 \quad 0 \quad 0 \quad 5000 \quad 5000 \quad 5000 \quad 5000 \quad 5000 \quad 5000$$
$$\ldots \quad 5000 \quad 5000 \quad 5000 \quad 5000 \quad 25000 \quad 25000 \quad 25000 \quad 25000 \quad \ldots \quad \text{NbAff}/5\ \Big]$$

It is assumed that aid demands are confined to requests for 8 items. Table 12.2 lists the specific parameters of the products studied. Only the quantities change in response to the crisis intensity, type and location. Weights of products may vary, from 0.14kg for jerry cans to 1133kg

Algorithm 1: Construction of the demand per products, region and time to respond to all crisis starting at t0

Input:

- Disaster-List, a list of past disasters, detailing for each Crisis$i$ the starting date (TimeCrisis[i]), the type (TypeCrisis[i] = earthquake, flood , etc.), the region affected (Region[i]) and the total number of people affected (NbAff[i]).
- Needs[p][CrisisType][c], which details which products (p ∈ [0..7], from cholera kits to mosquito nets) are needed for each crisis type and region c. For example, Cholera kits are needed for an epidemic in Western Africa, but not for a Storm in Northern America.

Output: D[p][c][t] which gives the cumulated number of each products p to send to regions c at times t (t ∈ [t0..t0+50] in our study, which represents one and a half month of relief operations to respond to all crisis occurring at a given time t0)

initialisation : nbAffTot = 0 ; for each p, c and time, D[p][c][time] = 0;
foreach *Crisis i within Disaster-list* **do**
  if *TimeCrisis[i]=t0* **then**
    Region *c* = Region[i];
    nbAffTot = +=nbAff[i];
    foreach *Product p* **do**
      if *NbAff[i] ≥ NbRescuedAtTime2* **then**
        foreach *time t ∈ [t0 +Time1.. t0 + Time2]* **do**
          D[p][c][time] = += nbRescuedAtTime1 * Needs[p][crisisType][c];
        foreach *time t ∈ [t0 + Time2.. t0 + Time3]* **do**
          D[p][c][time] = += nbRescuedAtTime2 * Needs[p][crisisType][c];
        foreach *time t ∈ [t0 + Time3.. t0+ nbT]* **do**
          D[p][c][time] = += NbAff[i]* Needs[p][crisisType][c;;
      else if *NbAff[i] ≥ NbRescuedAtTime1* **then**
        foreach *time t ∈ [t0 +Time1.. t0 + Time2]* **do**
          D[p][c][time] = += nbRescuedAtTime1 * Needs[p][crisisType][c];
        foreach *time t ∈ [t0 + Time2.. t0+ nbT]* **do**
          D[p][c][time] = += NbAff[i]* Needs[p][crisisType][c];
      else
        foreach *time t ∈ [t0 + Time1.. t0+ nbT]* **do**
          D[p][c][time] = += NbAff[i]* Needs[p][crisisType][c];

for medical kits. These products and their measurements are based on the recommendations of the IFRC, which considers them the most important resources for pre-positioning.

Table 12.2: List of products

Description	Purchase Cost (CHF)	(€)	Weight (kg)	Volume (m^3)	Packaging (nb beneficiaries per pack)
Woollen blankets	4	3	2	0,008	20
Plastic sheeting	150	109	55	0,18	40
Interagency Emergency Health kit	10935	7982	1133	5,85	10000
Cholera kits	2855	2084	1078	4,45	1200
Mosquito nets	5	4	4	0,0017	2
Hygienic parcels	4	3	0,44	0,01	5
Kitchen kits	19	14	4,7	0,022	5
Jerrycans (foldable)	3	2	0,14	0,00042	2

12.2 Suppliers

The actual suppliers are already known, as is a list of countries in which the suppliers of each item are located.

Each supplier cannot furnish all of the products. For example, in the UK, there are suppliers of plastic sheeting (P1) and jerry cans (P7), but not of other products. But if the crisis occurs in Africa, then the British Red Cross is usually a product donor. In this case, therefore, any region may receive P1 and P7 from England, but for all other products, supply is only possible in response to disasters affecting Africa.

At this level, our hypothesis presumes that the suppliers stocks are unlimited and can meet any demands from the warehouses. No specific constraints have been considered regarding the handling of these products. To better fit with reality, restrictions could have been placed on the locations of warehouses, so that medicines would not be stored in countries that that are too hot or too humid, for example. As we are initially locating warehouses on a regional level, however, this cannot be taken into account by the model.

What can and should be considered, however, is the location of future suppliers. Indeed, as we explained in chapter 9, if humanitarian organisations choose to decentralise their logistics networks, then this facilitates fast and adequate responses, in addition to building local capacities and strengthening local economies.

In this regard, however, humanitarians differ in their opinions. Whereas Oxfam, for example, has built a strong network of local suppliers and has close to 100% of its relief items produced in Africa, World Vision International regards the potential for local supply in Africa as - limited, especially when compared to the much greater opportunities available in Asia. (source = practitioners interviews)

The potential for local supply will therefore require additional study, in order to determine the impacts that changes in supply strategy might exert upon the design of the network.

12.3 Potential warehouses

As we explained in the Introduction, our mixed-integer linear programme locates the optimum number and location of regions that are capable of hosting a warehouse. Exact locations will then be decided by a multi-criteria analysis in chapter 14.

The definitions of regions correspond to those chosen for end users, that is to say 21 regions distributed as shown in Fig 12.1 on page 114. In the model described here, limits can be imposed upon the number of products that may be transited or stocked by a warehouse each day. This will therefore demonstrate how the size of warehouses impacts upon the results.

It is also possible to choose the size of the initial, contingency stock, in order to study its influence upon the costs and the effectiveness of the responses.

12.4 Objective function and constraints

Our objective is thus to maintain a given level of service, in terms of effectiveness and responsiveness, but at a reduced cost. Satisfaction of demand is therefore a constraint, and minimisation of costs is the objective.

Consideration is also given to the delivery times and costs, firstly between the suppliers and the warehouses, then between the warehouses and the clients. In addition, two means of transportation are possible, either by air or by sea. Air transportation, faster but more expensive than boat, is usually deployed during the first days of response. Transportation by ship often proceeds in parallel, but arrives later due to the longer delivery times.

The costs of delivery from suppliers to warehouses and then to final beneficiaries are not equal. Indeed, our interviews of humanitarian practitioners revealed that the costs of deliveries to an affected region may be as much as 4 or 5 times higher than standard rates, because of the lack of local delivery capacity and the competitiveness between organisations for the use of these scarce resources. Rates have been evaluated by cross-checking available databases from various transporters and validated by discussion with logisticians from MSF[1], WFP, the French Red Cross and international companies such as Nissan.

Purchase costs, as provided by IFRC emergency catalogues, as well as the fixed and variable costs of running the warehouse, have also been accounted for. These calculations were based on information regarding the average salary per hour and the GDP in the various regions.

As well as these real costs, a per diem penalty cost has been added to products that are not delivered on time. This 'stock-out' cost can be varied, in order to demonstrate its impact upon the outcome of the model. A high value of 1000 € per day and per product has been chosen, in order to ensure a high level of service.

As the construction of demand D_{pct} is detailed in this chapter and serves as input for this model, it must also be considered as a parameter.

12.5 Notations and model

12.5.1 Variables, parameters and indices

Table 12.3 on the facing page provides an overview of all the notations we use.

[1] Médecins Sans Frontière / Doctors without Borders

Table 12.3: Variables, parameters and indices

Notation	Nature	Definition
Indices		
p	p ∈ [0..7]	product
s	s ∈ [0..28]	supplier
w	w∈ [0..20]	warehouse
c	c ∈ [0..20]	"customer", i.e. affected region
t	t ∈ [0..nbT]	time
Parameters		
coef	double	coefficient to enable the modification of IFRC contingency stock, to visualise its impact on outputs
$CostF_w$	double	Fixed costs to run the warehouse
$CostV_w$	double	Variable costs to run the warehouse
D_{pct}	double	Demand of each product to rescue the affected region c at time t
$DCBD_{pwc}$	double	Delivery cost in boat to deliver product p from potential warehouse w to customer c (Downstream potential warehouse)
$DCBU_{psw}$	double	Delivery cost in boat to deliver product p from supplier s to potential warehouse w (Upstream potential warehouse)
$DCPD_{pwc}$	double	Delivery cost in plane to deliver product p from potential warehouse w to customer c (Downstream potential warehouse)
$DCPU_{psw}$	double	Delivery cost in plane to deliver product p from supplier s to potential warehouse w (Upstream potential warehouse)
dim_p	double	to take into account to packaging of products (20 blankets per parcel for example)
$DTBD_{wc}$	double	Delivery time in boat to deliver a product from potential warehouse w to customer c (Downstream potential warehouse)
$DTBU_{sw}$	double	Delivery time in boat to deliver a product from supplier s to potential warehouse w (Upstream potential warehouse)
$DTPD_{wc}$	double	Delivery time in plane to deliver a product from potential warehouse w to customer c (Downstream potential warehouse)
$DTPU_{sw}$	double	Delivery time in plane to deliver a product from supplier s to potential warehouse w (Upstream potential warehouse)
M	double	initially used in constraint (15.7) without physical signification. Can also be used to limit the warehouse size, i.e. maximum number of products which can be in a warehouse in the same day
nbAffTot	integer	Total number of Affected
nbT	integer	Duration of operations
QS_{pw}	double	IFRC Contingency stocks. Corresponds to a quantity of products p to keep in stock at warehouse w prior to disasters in order to enable an immediate response (5days)
S	double	Penalty costs, per day and per product not delivered on time
Variables		
QBD_{pwct}	double	Quantity of products p delivered at time t to customer c from w in boat
QBU_{pswt}	double	Quantity of products p delivered at time t to warehouse w in boat
QF_{ptc}	double	Quantity of products p delivered at time t to the region c
QP_{ptw}	double	Quantity in stock of products p in w at time t
QPD_{pwct}	double	Quantity of products p delivered at time t to customer c from w in plane
QPU_{pswt}	double	Quantity delivered from supplier to warehouse w in plane
$Stockout_{pct}$	double	Quantity of products p which were not delivered to customer c at time t
WCh_w	boolean	WChw=1 if the warehouse w should be opened ; WChw=0 otherwise

12.5.2 Objective function

$$
\begin{aligned}
Min \quad & \left(\sum_p \sum_s \sum_w \left(DCPU_{psw} \times \sum_t QPU_{pswt}\right)\right) + \left(\sum_p \sum_w \sum_c \left(DCPD_{pwc} \times \sum_t QPD_{pwct}\right)\right) \\
+ \quad & \left(\sum_p \sum_s \sum_w \left(DCBU_{psw} \times \sum_t QBU_{pswt}\right)\right) + \left(\sum_p \sum_w \sum_c \left(DCBD_{pwc} \times \sum_t QBD_{pwct}\right)\right) \\
+ \quad & \sum_w (CostF_w \times WCh_w) \\
+ \quad & \sum_t \sum_w CostV_w \times \left(\sum_p \sum_s (QPU_{pswt} + QBU_{pswt}) + \sum_p \sum_c (QPD_{pwct} + QBD_{pwct})\right) \\
+ \quad & \sum_p \sum_w \sum_c \sum_t (Stockout_{pct} \times dim_p \times S) \qquad (12.1)
\end{aligned}
$$

Where

- Line 1 represents transportation costs by air, from supplier to warehouse and from warehouse to customer.
- Line 2 represents transportation costs by boat, from supplier to warehouse and from warehouse to customer.
- Line 3 represents the fixed costs of maintaining a functioning warehouse.
- Line 4 represents the variable costs incurred in running the warehouse. It is proportional to the quantity of products; the greater the number of products handled by the warehouse, the greater the number of employees required.
- Line 5 represents the penalty cost incurred if products are not delivered on time.

12.5.3 Constraints

Definition of the cumulated quantities of products delivered to the affected regions

For each affected country, for each of the products studied, and each time t, the cumulated demand at t is the sum of all items that have arrived by plane or by boat, from any of the opened warehouses, from the moment the disaster struck until the time t.

$\forall p, c, t = 0$

$$QF_{pc\,0} = \sum_w QPD_{pwc\,0} + \sum_w QBD_{pwc\,0} \qquad (12.2)$$

$\forall p, c, t \geq 1$

$$QF_{pct} = QF_{pc\,(t-1)} + \sum_w QPD_{pwct} + \sum_w QBD_{pwct} \qquad (12.3)$$

Satisfaction of the demand

The quantity of products delivered should be equal to the demand. It may be slightly higher, if the total number affected is not a multiple of the packaging of product. It may also be lower as a consequence of stock-out.

$$\forall p, c, t$$
$$QF_{pct} \geq D_{pct} - Stockout_{pct} \tag{12.4}$$

Products can go via a warehouse only if it is opened

If a warehouse w is not opened, then $WCh_w = 0$, as the quantity of products delivered to or sent from this warehouse w is null, whatever the means of transport.
If w is open, then $WCh_w = 1$, and products can be delivered to or sent from this warehouse w. M has no physical signification. Its value is chosen high enough to enable the needed quantity of product to transit within the warehouse w. If the chosen value is too low, it acts like a constraint on the size of the warehouse (in which case, the total number of items allowed to transit through the warehouse has an upper bound, M)

$$\forall w$$
$$\sum_p \sum_t \sum_c (QPD_{pwct} + QBD_{pwct}) \leq M \times nbAffTot \times WCh_w \tag{12.5}$$

In our model, from one scenario to another, the quantity of products transiting may vary from 10^2 to 10^{11}, depending on the total number affected. Our first attempt was to choose$M = 10^{11}$, in line with the maximum quantity of products which may be needed in the case of a large disaster. With this value, products were transited through closed warehouses. This is due to the fact that, for our programming language (java), everything below 10^{-5} was considered as 0. 10^5 is thus considered negligible compared to 10^{11}. Yet to have tens of thousands of items transiting many parts of the world without a warehouse officially open is unacceptable.

A reference was therefore added to the numbers affected, so that the left-hand side of the equation remains constant throughout the scenarios, and allowing a value to be chosen for M that fits whatever quantity of products is transiting the opened warehouses.

Inventory balance

At t=0, the contingency stock QS_{pw} is maintained in every opened warehouse.

For every$t > 0$, the items in the warehouses are the same as the previous day, plus new items received from suppliers, minus items dispatched to the affected region. $thefourvariablesQPD_{pwct}$, QBD_{pwct}, QPU_{pswt} and QBU_{pswt} are quantities delivered. So the quantities, which leave the warehouse at t, are delivered at $(t + DTPD_{pwc})$ for air deliveries and $(t + DTBD_{pwc})$ for deliveries by sea.

$$\forall p, w, t = 0$$
$$QP_{pw0} = QS_{pw} \times WCh_w \forall p, w, t \geq 1$$
$$QP_{pwt} = QP_{pw(t-1)} + \sum_s QPU_{pswt\ (\text{ if } t>DTPU_{wc})} + \sum_s QBU_{pswt\ (\text{ if } t>DTBU_{wc})}$$
$$- \sum_c QPD_{pwc(t+DTPD_{pwc})} - \sum_c QBD_{pwc(t+DTPD_{pwc})} \tag{12.6}$$

Rebuilding contingency stock after the end of operations

The contingency stock may be used to quickly send items to the affected regions. It should be rebuilt at the end of relief operations in order to ensure that the victims of future disasters can again be rescued with sufficient haste.

$$\forall p, w$$
$$QP_{pwnbT} = QS_{pw} \times WCh_w \tag{12.7}$$

No reception before delivery times

Delivery from one region to another takes time. No product can arrive before this delivery time.

$$\forall p, s, w, t \leq DTPU_{sw}$$
$$QPU_{pswt} = 0 \tag{12.8}$$
$$\forall p, s, w, t \leq DTBU_{sw}$$
$$QBU_{pswt} = 0 \tag{12.9}$$
$$\forall p, s, w, t \leq DTPD_{wc}$$
$$QPU_{pwct} = 0 \tag{12.10}$$
$$\forall p, s, w, t \leq DTBD_{wc}$$
$$QBU_{pwct} = 0 \tag{12.11}$$

Taking into account existing IFRC network

IFRC has three regional warehouses already opened, in Panama (c=2), Kuala Lumpur (c=15) and Dubai (c=19). If these are to be taken into account, then constraint 14.13 is added.

$$\begin{aligned} WCh_2 &= 1 \\ WCh_{15} &= 1 \\ WCh_{19} &= 1 \end{aligned} \tag{12.12}$$

Should we want to limit the number of warehouses to open

If limits are to be placed on the number of warehouses opened, then constraint 14.14. is added. In this example, no more than 4 different warehouses are to be used in any given scenario.

$$\sum_w WCh_w \leq 4 \tag{12.13}$$

Additional remarks

We also decreased the total number of variables per scenario. Indeed, from one scenario to another, the list of region affected differ, and so does the list of product needed and so on. We therefore added a function which, for each indices, reduces the range of possible values to the ones really used.

13

Analysis

Our application focuses on the lists of products and suppliers defined by the IFRC. While this model can be readily applied to other agencies with different data and parameters, the conclusions presented here are only valid for this one, specific application. Indeed, the same study would differ for MSF, for example, which supplies medical treatments that often demand special storage and transport; criteria that are not accounted for by this model. MSF also have more limited opportunities for local sourcing, as manufacture of patented medicines is often confined to specific countries or regions. Simulations for UNHRN[1] and World Vision are on-going.

Data values employed can be found in the appendix. As described briefly in previous chapters, most of this information derives from interviews and public databases. Transportation costs and times have been based on quotes provided by a major U.S. transportation company, independently validated by discussions with practitioners from MSF and two private companies [Wor10]. Fixed and Variable costs have been calculated on the basis of regional average salaries and GNI/GDP[2]. Information regarding purchase costs and the locations of suppliers has come from our interviews and the IFRC website. Initial values of certain parameters, such as the required level of service and the size of the contingency stock, also derive from discussions with IFRC.

Figure 13.1 on the next page details all the questions that will be discussed in this chapter.

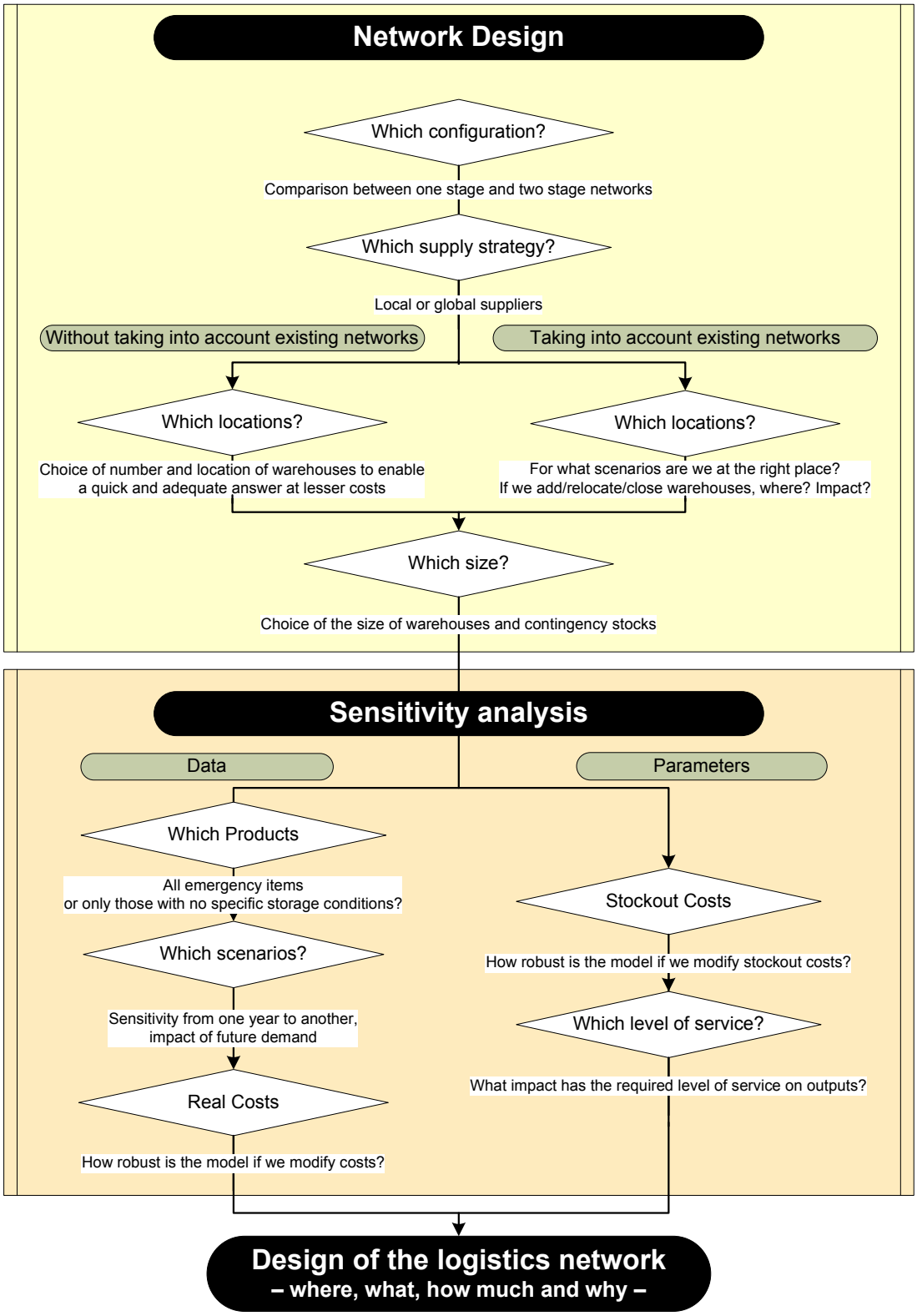
The Analysis is divided into two parts :

1. Practical answers to organisations' questions regarding the design of their logistics networks. These include answers to questions such as how many stages should a network have? How many warehouses should be maintained, where should they be located and what size should they be? How many items should be kept in stock by each warehouse to enable a swift response?

2. Sensitivity analysis, both to strategic decisions impacting available choices and to various parameters used in our model.

[1] the UN humanitarian response network
[2] Gross National Income/Gross Domestic Product

Figure 13.1: Overall view of our research questions



The answers to the above questions depend upon many decisions and parameters. If there is an intention to use local suppliers and so develop local networks in each warehouse, then the costs and delays involved in sending resources to the affected regions will differ from those of an organisation that employs global suppliers. The range of items supplied is a further major variable, because the locations of their suppliers influence how a network design evolves. Furthermore, some of these input parameters, such as transportation costs, may be fixed by external organisations without consultation or dialogue, whilst others may evolve through mutual interests. In addition, agreements with national governments and other agencies to maintain stock levels at specific locations may influence the costs of operating in individual countries. How sensitive will the model prove to all of these cost variations? This question will be addressed in section 13.5.4 on page 142.

In the context of cost-evaluation, our model includes a "stock-out cost" that accrues if the demand is not satisfied on time. A high figure has been deliberately chosen to reduce the risk of delay. The “level of service” targets of the IFRC have also been employed to define satisfactory levels of response within 5 and 15 days. Sections 13.5.5 on page 143 and 13.5.6 on page 144 will clarify the impacts of these various choices in terms of levels of service. Finally, section 13.5.2 on page 140 will analyse the impact of foreseeable changes in disasters nature, number, intensity and location on the design of the logistics network.

13.1 Which network configuration and supply strategy?

13.1.1 Impact on costs and level of service

Many configurations are possible. The logistics network can have one, two or more stages. Most humanitarian networks actually have only one stage (see case n°1, figure 13.2). If additional warehouses are added on a local level, they can function in the same way as existing regional warehouses (case n°2a, figure 13.2), with global suppliers sending items directly to small, local warehouses, or an additional level can be added to the network, in which case regional units act as suppliers for local warehouses (cases n°3a and 3b, figure 13.2). Cases 1b and 2b are variants of cases 1 and 2, but they include the possibility of adopting local suppliers.

Each case has its advantages and weaknesses (see chapter 9). Table 13.1 compares available options in terms of costs and level of service. For each case, there is one run of the program per scenario. The costs of the response of each scenario is then summed to get the "Total costs" over one year. "Possible savings" are then calculated to visualize the consequence of a change in the configuration of the network. The cost to respond to crisis with the existing network (Case 1a) serves as reference. Figures for stock-out are calculated on the same basis : one run per scenario. The few scenarios with stock-out are the summed to get the total stock-out.

As expected, for a one-stage network, reworking the configuration can improve both costs and the level of service (from case 1 to case 2). Case 2 being an optimal network, redesigned for each scenario, it only provides the lowest possible bound, not the lowest achievable bound. Still, there is room for improvement, which will be further analysed in the following section.

If we now compare networks with one or two stages, here again we find that results are in line with common sense. A decentralised network with two stages costs more than a centralized network. With regard to IFRC specifications for the level of service this additional layer is unnecessary, as a single stage network is sufficient to ensure the desired levels of service in every scenario. The impact of these modifications upon level of service targets will be analysed in section 13.5 on page 139.

Figure 13.2: Which configuration for the network?

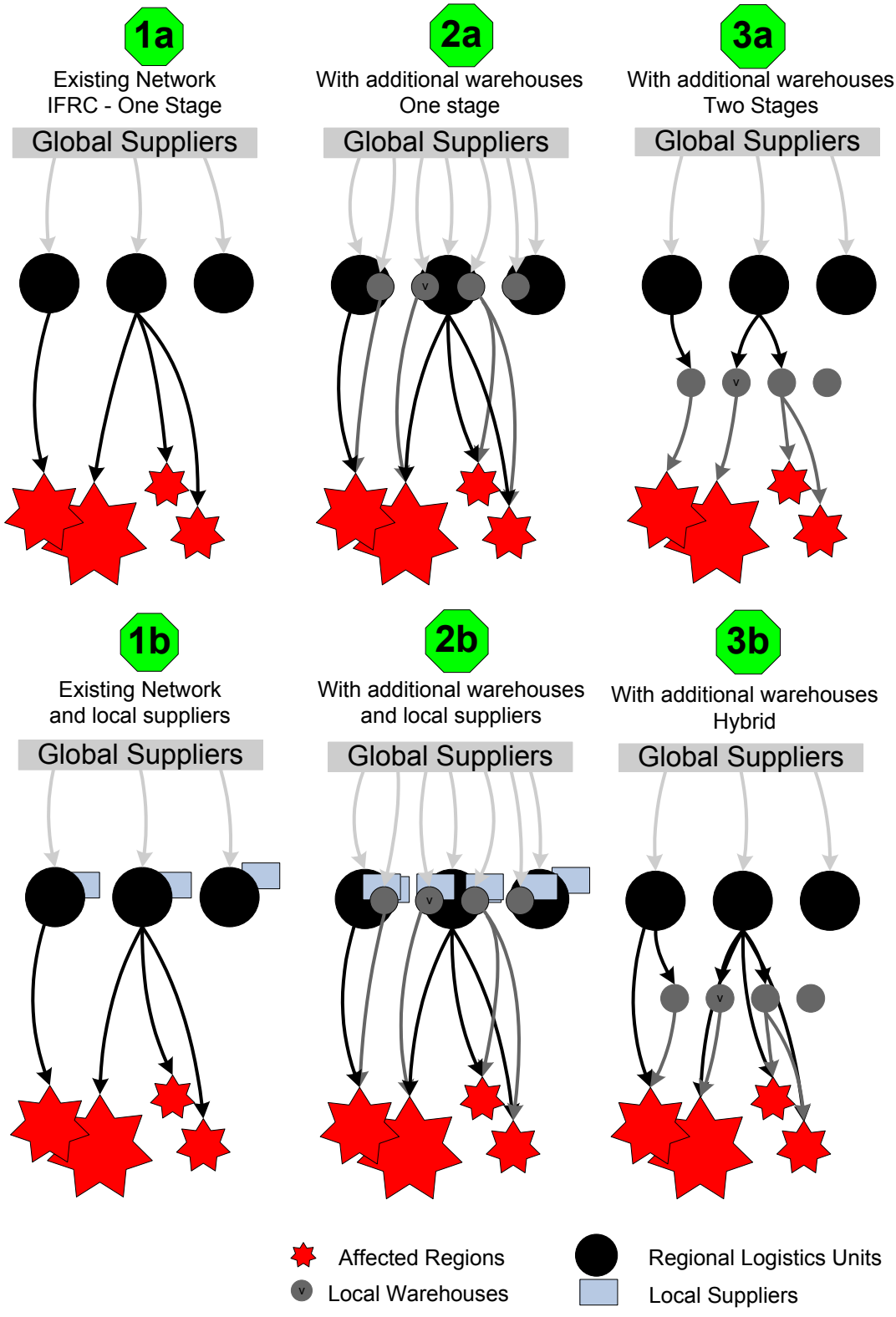


Table 13.1: Comparison of possible options for the configuration of the logistics network
The total is done over one year, for the immediate response to every natural crisis with more than 100 affected

	Case 1a	Case 2a	Case 3a	Case 1b	Case 2b	Case 3b
	Global IFRC Suppliers			Local Suppliers		Supply by RLU Hybrid
	Existing Network (IFRC)	One stage optimal	Two stages optimal	Existing Network (IFRC)	One stage optimal	
Total costs (€)	11,3E+09€	10,0E+09€	13,4E+09€	10,2E+09€	8,77E+09€	12,9E+09€
Possible savings	0%	12%	– 19%	10%	22%	– 14%
Percentage of scenarios with stock-outs	3%	0%	0%	0%	0%	0%
Total stock-out (nb products late x nb days waiting)	878 605	0	0	0	0	0

These results suggest that, in terms of costs, a configuration with only one stage is more effective. Consequently, the detailed analysis that follows will only focus on one-stage networks. The impact of varying the numbers and locations of suppliers will be discussed, and the influence that these factors exert upon the number, location and size of warehouses will also be examined.

When the possibility of purchasing supplies locally is introduced, (case 2b), then the costs are – not surprisingly – lower. Levels of service also appear to improve, but this is because no limits were set on the presumed capacities of local suppliers. Being nearer, delivery times from such suppliers are shorter and hence their costs are also reduced. But a situation in which 100% of supplies are locally sourced may not be relevant in every region. “Frequently, local availability of specific items is low or unpredictable, or the quantity and quality of locally available products is not good enough to meet needs efficiently” [Org01] (See chapter 9 on page 91).

13.1.2 Impact of configuration and supply strategy on number and location of warehouses needed

With actual suppliers

If there is no possibility of obtaining local supplies, then for crises affecting fewer than 10,000 individuals the Caribbean offers the best locations for maintaining stock.

As these comparatively small crises represent a large proportion of the disaster scenarios modelled, then because of their frequency, the Caribbean is often found to be the warehouse area that is most often running (see figure 13.4 on page 129). For small crises of this type, either with or without the potential for local supply, those locations that are cheapest in terms of running costs are chosen.

Indeed, as there are few products to deliver and hence lower delivery costs, the sensitivity of the model regarding fixed costs is higher in such cases, as they represent a higher proportion

of the total costs. This sensitivity to fixed costs is detailed in section 13.5 on page 139. Apart from the Caribbean, the principal locations chosen with the actual global suppliers of the IFRC, (who also supply other international NGOs), are as follows:

1. South-Central Asia (15% of the scenarios)
2. South-East Asia (9,5% of the scenarios)
3. East Africa (9% of the scenarios)

With local suppliers

If there is a possibility of obtaining supplies locally, (in the region where the warehouse is located), and if the model is allowed to choose the best spot within each scenario, then the region in which the largest crisis occurs is chosen for 72% of the scenarios. Such local warehouses need the support of a second warehouse in 16% of cases. The only crises for which a global warehouse is the preferred option are those of very small size, with fewer than 10,000 individuals affected.

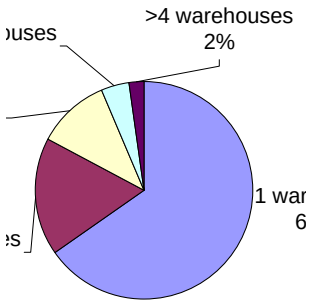
The chosen warehouses are the same than as with global suppliers, though not with the same proportion, as they are all equally used in this configuration.

With or without the possibility to supply locally, the program chooses the same locations. The only difference is that, with local suppliers, no one warehouse is used more than another, whereas with global suppliers, one warehouse (south-central Asia) is preferred. The fact that the locations chosen are the same, with or without the possibility to supply locally means that the logistics network built with only global suppliers will still be optimal once the local network is developed. This is extremely important, due to the fact that the possibility to supply locally is uncertain in most of the regions. It may exist, but it is difficult to assess if you don't have local resources, experience or a network. According to the program, it is possible to choose your locations first, and then work on you supply strategy and build local capacity. You will still have your warehouses at the best locations.

The number of warehouses required also tends to fall if local supplies can be arranged. As total delivery time from supplier to warehouse reduces, correspondingly greater time becomes available for the warehouse to deliver aid supplies to the affected regions. It thus becomes possible for warehouses to service disasters at progressively greater distances, without any reduction in the levels of service.

Figure 13.3: Number of warehouses needed depending on the possibility to supply locally

(a) Without local suppliers



(b) With the possibility to supply locally

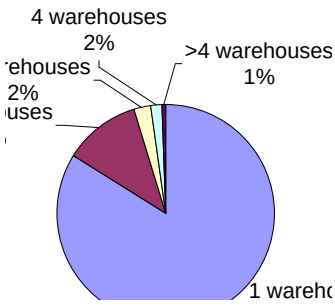


Figure 13.4: Location of warehouses depending on the supply strategy
173 runs corresponding to the natural crisis of year 2008

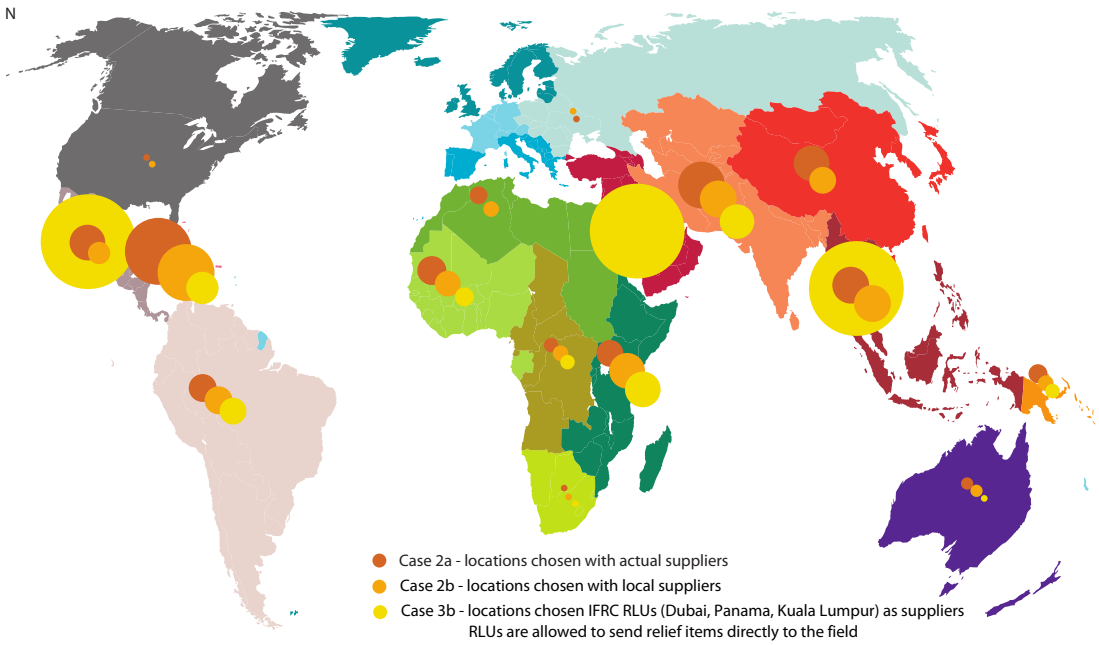
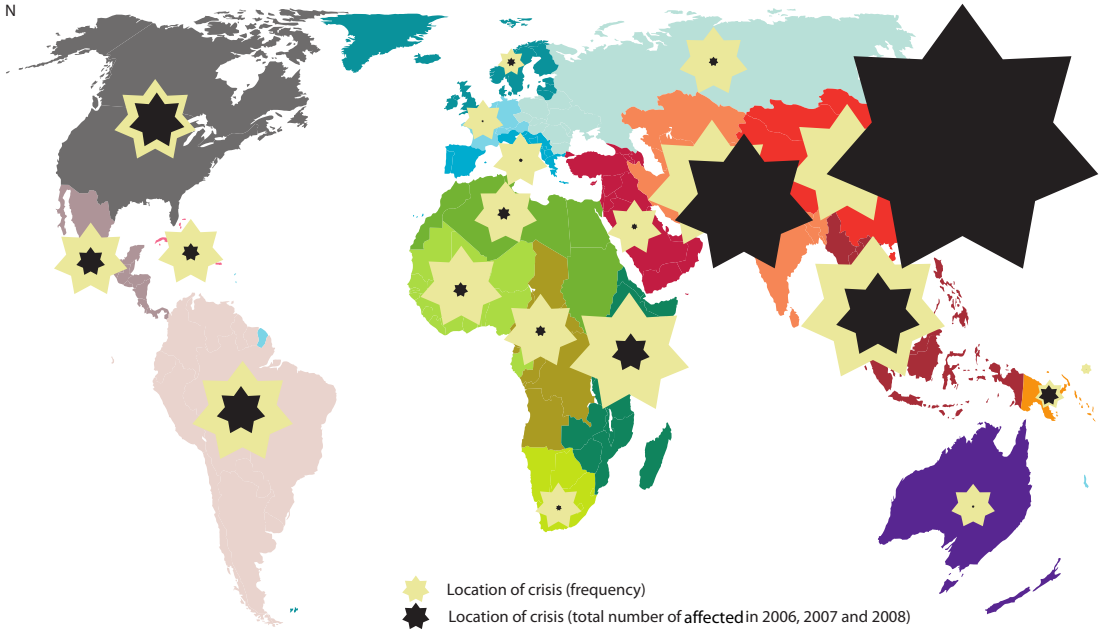


Figure 13.5: Reminder - Location of crisis (number and impact), to enable a comparison with location of warehouses



With the supply done by the three regional warehouses in Dubai, Panama and Kuala Lumpur

With regard to locating sub-regional hubs, if we consider running a two-stage network, and thus impose a restriction that the local hub should be supplied by the three Regional Logistics Units of the IFRC, then the best regions to add these additional local warehouses would be in East Africa (in 23% of scenarios), South-Central Asia (22%) and the Caribbean (20%). A similar result to this last case can be achieved by doubling the capacity of the regional hub in Panama. This corresponds to case 3b of figure 13.2 on page 126. Figure 13.4 on the previous page illustrates the impact of supply strategy upon the choice of the location of warehouses. Figure 13.5, provides better comparison between the locations of warehouses and the locations of crises.

If RLUs[3] are not allowed to send relief items to the field to complement those from local warehouses (case 3a), then these same three warehouses remain the best locations - but in opposite order. An additional warehouse is also needed in South-Eastern Asia.

13.2 Discussions on network design, without taking existing networks into consideration

The previous section provided some observations regarding costs, levels of service, the numbers of warehouses involved and their locations, as well as noting the influences that derive from supply strategy. This section will also discuss the best locations for opening a warehouse, but with other strategic decisions in mind. Natural crises, such as the small to medium-size disasters which does not always generate a response from INGOs[4] do not require identical logistics networks. Other parameters that may affect the choice of location may include the presence of existing warehouses and the number of warehouses that are allowed to send relief items in response to a given crisis.

13.2.1 Number of warehouses needed

In order to respond to the disasters that occurred in 2008 within IFRC specifications (25,000 rescued within 5 days, 75,000 within 15 days and the total number of affected within 2 months), our model required only one warehouse in 66% of cases (see figure 13.3 on page 128). These consisted mainly of small to medium-sized crises. The model indicates that, where fewer than 100,000 individuals are affected per annum, a local warehouse is not efficient.

An examination of the correlation between the number of warehouses required, the number of individuals affected and the number of disasters occurring within a given scenario indicates that the number of warehouses required is more dependent upon the number of operations that must be managed in parallel than on the size of the disaster (see table 13.2).

[3] Regional Logistics Units - IFRC existing network -
[4] International Non Governemental Organizations

Table 13.2: Correlations - Without the two biggest disasters

	C1	C2	C3	C4
C1 : Number of affected by the disaster	1			
C2 : Number of affected regions	0,3	1		
C3 : Number of warehouses needed	0,5	0,7	1	
C4 : Total real costs	0,97	0,3	0,5	1

Even if it were the case that one warehouse was sufficient for every scenario, and if the program were allowed to change the warehouse location for each different scenario, it would not address the question of the optimal number of warehouses required to achieve a rapid and efficient global response.

Responses were therefore simulated with various network configurations, but in these cases imposing restrictions on the numbers and locations of warehouses, to allow comparisons between the various options with the aim of finding the optimal, achievable solution.

The answer to this question depends on the targeted level of service. If we consider that an immediate response meeting IFRC levels of service for 10% of relief operations is sufficient, then two warehouses would be optimal. The model recommends locating one warehouse in the cheapest accessible location, and the other in locations close to the regions in which the highest numbers of individuals are affected per year, such as South-Central Asia or South-East Asia.

In order to reduce the frequency of stock-out, a third warehouse in either East or West Africa will limit the proportion of such scenarios to 3%.

For the number and location of warehouses needed with a higher targeted level of service, see section 13.5.6 on page 144.

13.2.2 Optimal locations

Locations chosen depending on the number of affected per scenario

A look at disaggregated results shows that at least one of the chosen warehouses is local in 57% of the cases. This percentage is true when only one region is affected in the scenario. It is also true when two or more regions are affected, in which cases half of the scenarios require at least one warehouse in one of the affected areas.

In the case of scenarios involving multiple simultaneous disasters, with two or more crises affecting more than 4,000 individuals, the most efficient solution is to use a warehouse located somewhere between the affected regions. In cases involving a smaller number, a location with low running costs is better.

All in all, if a response is expected for every natural crisis affecting more than 100 people, then the best choices of warehouse location are the Caribbean, (in 31% of scenarios), South-Central Asia (15%), South-East Asia (9,5%) and East Africa (9%). If the intention is to only respond when more than 100,000 individuals are affected, then the two best locations are South-Central Asia (19%) and East Asia (17%).

Figure 13.6: Location of warehouses depending on the decision to respond to all crisis or only to the bigger ones
173 runs corresponding to the natural crisis of year 2008

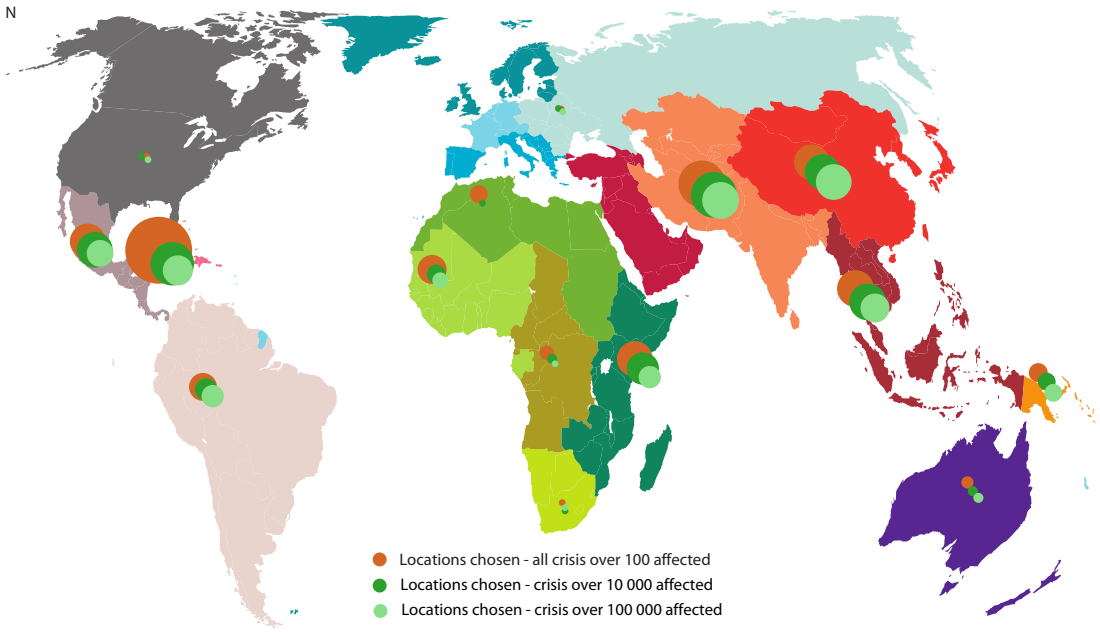


Figure 13.6 illustrates how the number of individuals affected per scenario impacts on warehouse locations.

And if we limit the number of warehouses allowed per scenario?

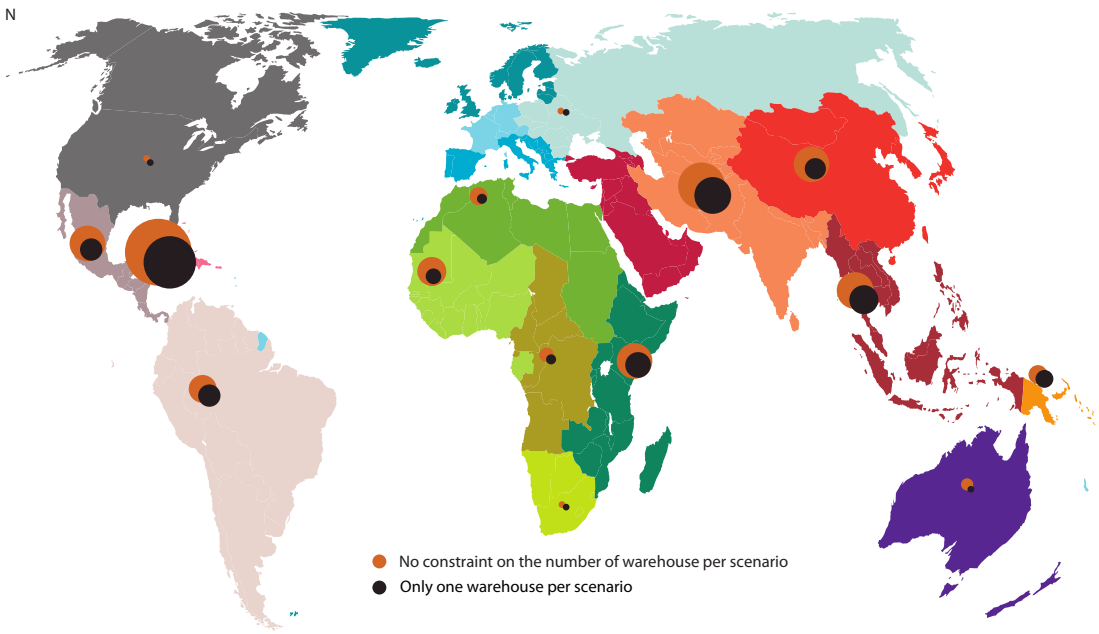
Depending on the constraints imposed on the network, the locations chosen may vary slightly. Figure 13.7 allows us to visualise how the number of warehouses impacts upon the locations chosen.

More generally, as is shown by a comparison with figure 13.5 on page 129, optimum locations do not always correspond to regions of higher crisis rates, especially in the case that is constrained to use only one warehouse for responding to all of the crises in a scenario. Asian regions are nevertheless most commonly chosen, as most of the crises also occur in these areas.

For these single warehouse scenarios, it is again found that the Caribbean is an optimal location for responding to small crises. South-Central Asia is also chosen as an optimal location in each case, whatever number of warehouses the scenario permits.

Some changes are nevertheless seen when this constraint on the total number of warehouses is added and used in parallel. Indeed, West Africa, which did not appear to be a good location without this limitation, now appears within the top three optimal locations. Its situation, between Asian and African countries, renders it the “best compromise” when only a limited number of warehouses can be opened and maintained. This is true when we consider all of the scenarios, and it is also true when the study is limited to the largest disasters only, involving more than 100,000 individuals per scenario. (For 9 to 10 % of the scenarios, if only one warehouse can be used, then it should be situated in West Africa).

Figure 13.7: Location of warehouses depending on the number of warehouse running in parallel
173 runs corresponding to the natural crisis of year 2008



Western Asia, on the contrary, appears to be a poor choice. Most humanitarian organizations have pre-positioned resources there, attracted by the free zones and the proximity of other aid organisations. In locating there, however, they have overlooked the fact that transportation costs are often much higher than the fixed and variable costs associated with running a warehouse.

This point deserves further discussion. The model presented here did not take into account any of the negotiated agreements that exist within these countries, nor did it incorporate the possibilities for decreasing fixed costs by choosing the same location as other NGOs. The fixed costs used by our model in Western Asia are therefore higher than the real fixed costs encountered in the free zone - in Dubai for example. Section 13.5.4) provides a detailed analysis on the impact of fixed costs on the results.

13.3 Network design taking into account existing network

The previous section provided recommendations regarding the optimum design of humanitarian supply chains, without taking existing networks into consideration. This section will work the other way around, providing management recommendations regarding modification of the existing network, as designed by IFRC.

From section 13.1 on page 125, we can recommend not to add an additional layer to the network without the possibility to supply locally. According to table 13.1 on page 127, a new stage supplied by RLUs would increase costs by 14% with no real benefit in terms of level of service. This section analyses various improvement possibilities.

13.3.1 Best candidates for the opening of an additional warehouse

Looking at the optimum locations for building additional warehouse(s) to supplement an existing network, these optimal locations are consistent with previous results. If we are to complement the three IFRC RLUs[5], then the next optimal locations remain South-Central Asia, followed by East Africa.

With respect to the Caribbean, as there is an existing warehouse situated in Panama, this becomes a less relevant location, appearing only 6th in the rankings.

Table 13.3 on the facing page compares costs and levels of service between networks with 2, 3 , 4, 5 or 6 warehouses.

13.3.2 How many additional warehouses to add if the actual network is kept as such?

As can be seen, opening an additional warehouse in South-Central Asia would be more effective globally, in terms of both costs and levels of service. Indeed, as many disasters occur in this region, transportation costs would correspondingly decrease if resources were already pre-positioned there, especially knowing that some of the global suppliers are also located in this region. Globally, these savings in transportation costs are higher than the increase in operating costs incurred through opening this additional warehouse. Opening two additional warehouses, in South-Central Asia and East Africa would be even better, although close to the results observed with 4 warehouses.

With the possibility that three warehouses might be added, here again, the network would improve globally, but not by much. The level of service would only be improved slightly, without additional costs.

By adding further additional warehouses we only increase global capacity marginally. Instead of opening new warehouses, one option for improving the network would be to simply increase the existing contingency stocks. In terms of level of service, three large or six small warehouses are equivalent, but in terms of overall costs, placing additional locations closer to the field is more effective.

13.3.3 Modifying the existing network ?

As for the possibility of modifying the existing network, if we close the warehouse in Dubai, there would be a 5% decrease in costs. This is not a significant saving, especially when we consider that the level of service is also impacted.

If we relocate all of the warehouses the situation seems better than in the existing network, both in terms of costs and levels of service. It is not improved, however, when compared to a network comprised of 5 or 6 warehouses. Relocation, although theoretically possible in consequence of the small size of actual warehouses, would require additional analysis to be validated (see section 13.5 on page 139).

Indeed, local networks, both with suppliers and with other organizations, agreements with governments to decrease fixed costs as in Dubai, and many other elements linked with the

[5] the three Regional Logistics Units of the International Federation of the Red Cross and Red Crescent Societies

Table 13.3: Comparison of possible options to optimize existing network

Total Costs gives the total real costs (stock-out costs are not included) to respond to all natural crisis affecting more than 100 human being within a year, according to our model.

	Same locations than IFRC network			Change in locations of existing warehouses					
	No change	Bigger contingency stocks	Local supply	Plus one warehouse	Minus one warehouse	Plus 2 warehouses	Plus 3 warehouses	Relocate warehouses	Relocate + local supply
Western Asia	X	X	X	X		X	X		
Central America	X	X	X	X	X	X	X		
South-Eastern Asia	X	X	X	X	X	X	X		
South Central Asia				X		X	X	X	X
Eastern Africa						X	X	X	X
Carribean							X	X	X
Number of warehouses	3	3	3	4	2	5	6	3	3
Total real costs (€)	11,3E+09€	11,2E+09€	10,2E+09€	10,7E+09€	10,9E+09€	10,6E+09€	10,6E+09€	10,32E+09€	10,1E+09€
Possible savings (real costs)	0%	0,9%	9,7%	5,3%	3,5%	6,2%	6,2%	8,7%	10,6%
Percentage of scenarios with stock-outs	3%	0,5%	0%	3%	9%	2%	1%	3%	2%
Total stock-out (nb products late x nb days waiting)	878 605	56 808	0	168 916	2 319 460	88 926	56 808	358 620	98 421
Total costs incl. fictive stockout costs	1,22E+10	1,13E+10	1,02E+10	1,09E+10	1,32E+10	1,07E+10	1,07E+10	1,07E+10	1,02E+10
Possible savings (incl. Stockout costs)	0%	7,6%	16,25%	10,75%	– 8,55%	12,2%	12,5%	12,3%	16,3%

re localization of human resources have to be taken into consideration. These are tackled in section 13.5 on page 139.

Warehouse relocations would also mean that the local networks that presently exist around warehouses would be lost, with correspondingly detrimental impacts upon both costs and service. In fact, if a comparison is made between the actual network, run using local suppliers, and a modified network with better locations - but no local supply network - then the best option is to simply keep the existing warehouses.

13.3.4 Disaggregated results - Where is the actual network sufficient, and where should it be improved?

Let us now look at disaggregated results.

Figure13.8 illustrates the cost difference between the actual network of the IFRC and an optimized network, depending on the changes that are decided. This shows that opening one, two or three additional warehouses would be more expensive in two-thirds of the scenarios, but would still be justified by the large potential savings generated in cases of large-scale disasters. Scenarios with higher cost effectiveness involving additional warehouses are those in which many medium or large-scale disasters strike simultaneously, demanding more relief items. In such cases, however, the increase in the total capacity of the network has as much impact on the result as the additional geographical locations. As for relocating all warehouses, this could decrease costs in more than 90% of the scenarios.

Scenarios with higher cost-effectiveness involving two rather than three warehouses are those that include one or more very small crises, regardless of their locations. In these cases, where the aid quantities involved are small, delivery costs are less than the fixed costs associated with maintaining local stocks. As this happens frequently, a high number of scenarios suggest that considerable savings would be made if one of the RLU[6] were closed. This situation is rectified if we only consider natural crises affecting populations of more than 100,000 individuals, (see figure 13.8 on the next page)

Looking now at levels of service, scenarios in which the IFRC network cannot meet expectations occur when more than six operations are managed simultaneously, with two or more occurring in the same region. With respect to geographical location, the most difficult regions to reach on time are Melanesia and most of the African regions, (West, East and Central Africa).

The size of the contingency stock has been modified in order to visualize its impact on the choice of location. Various weighting factors have been applied to this contingency stock (QS) as initially defined by the IFRC (QS = items for 75,000 persons). Results have been obtained for situations in which the number of warehouses is limited to one per scenario, and no constraints have been applied to the number of warehouses that may be used, or their potential locations.

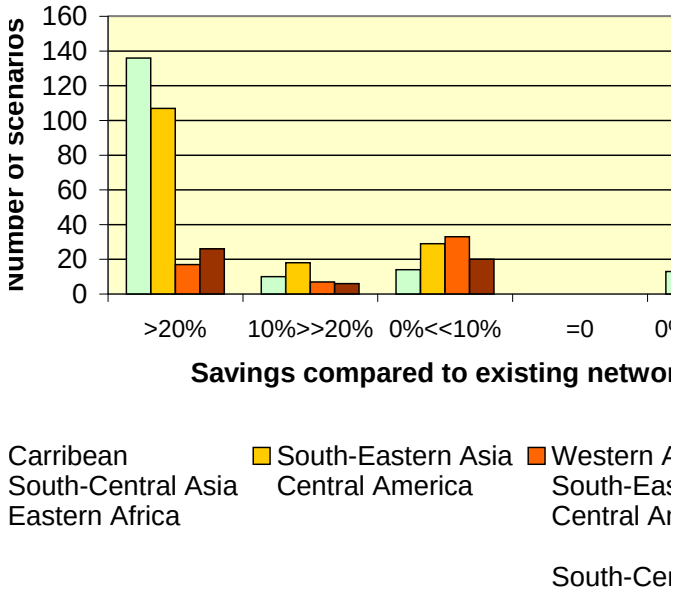
As table 13.4 on page 138 makes clear, increasing the size of the contingency stock decreases costs. Indeed, although maintaining stock is costly, inadequate pre-positioning of items will mean that supplies will have to travel longer distances. Meeting targeted service levels might therefore demand the use of expensive modes of delivery.

An increase in the size of the contingency stock also limits the mean number of warehouses employed per scenario. As might be expected, networks with higher contingency stocks also offer better levels of service.

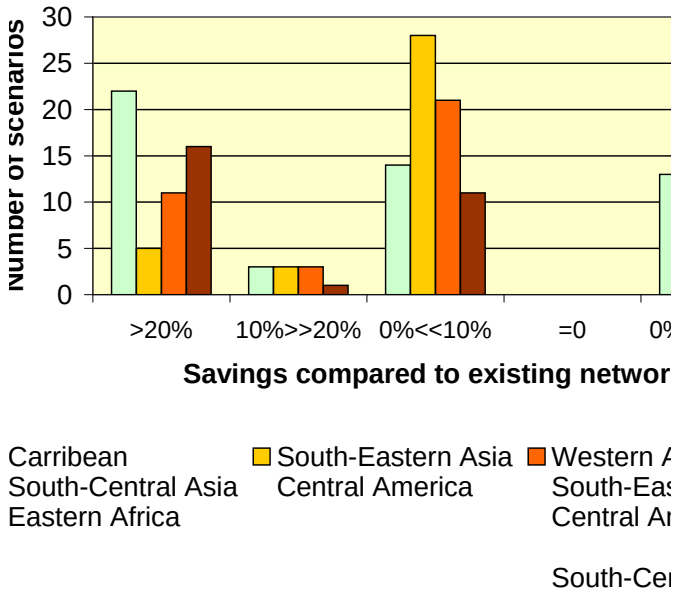
[6] Regional Logistic Unit, the three warehouses of IFRC in Dubai, Kuala Lumpur and Panama

Figure 13.8: Possible savings between actual IFRC network and optimized network, with current network plus/less one or more warehouses or with higher contingency stocks
Comparison is done for all scenarios build based on 2008 natural crisis

(a) Total Costs, including stock-out costs, **All crisis**



(b) Total Costs, including stock-out costs, **Medium and big crisis (> 100 000 Affected)**



On the other hand, if no contingency stock remains because it has already been assigned to another relief operation, and stocks were not re-built with appropriate haste, then more than 90% of the scenarios indicate that one or more products will not be delivered on time by the 5th day.

Consequently, in order to ensure that a given level of responsiveness and effectiveness can be maintained, it is better to have one well-managed warehouse than many small warehouses possessing no clear strategy for stock replenishment.

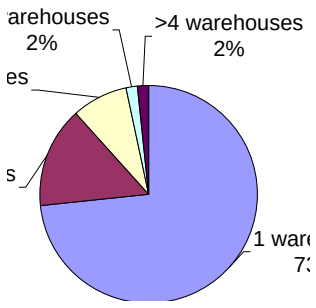
Table 13.4: Impact of changes on the size of the contingency stock

Number of warehouses	One per scenario		No constraint		Existing network (IFRC)	
Size of contingency stock	QSx1	QSx2	QSx1	QSx2	QSx1	QSx2
Total Real Costs (€)	11,78E+09	10,32E+09	9,54E+09	9,50E+09	11,26E+09	11,22E+09
Percentage of scenarios with stock-outs	25%	9%	0%	0%	3%	0,5%
Amount of stock-out (nb products late x nb days waiting)	2 866 019	909 931	0	0	878 605	56 808

13.4 Size of contingency stock and size of warehouses

With regard to the choice of location, the greatest impact of an increase in contingency stock can be seen in the Caribbean. Indeed, with a higher stock, fewer warehouses are needed: on average, the number of warehouses required decreases by 12% (see figure 13.9). This diminution holds true on each occasion involving two or more simultaneous crises, one of which was too small to justify a local warehouse, the other too big to allow the local warehouse to manage another crisis at the same time. With higher capacity, the warehouse responding to medium or large-scale disasters can also handle smaller crises. The additional location in the Caribbean is therefore no longer needed.

Figure 13.9: Number of warehouses needed with bigger contingency stock



Size of the warehouse

Unsurprisingly, if limits are placed on the capacities of warehouses then more warehouses are needed. It is also more expensive to have many medium warehouses than one central warehouse. Once again, the presence of many warehouses limits potential for scale-economies and also multiplies the fixed costs, so this result seems logical. In the case of very small

warehouses with handling capacities of around 10,000 products per day, it seems normal that the balance between global delivery capacity and needs is much more difficult to achieve. This explains the amount of stock-out for small warehouses. Furthermore, no constraint was set on the location of warehouses, only on their capacities. For each scenario, therefore, one local warehouse is used. If they are compared with results for one warehouse in south-Eastern Asia for each of these scenarios, the costs are increased and the levels of service are lower.

Table 13.5: Impact of changes on warehouse delivery capacity

	Optimal network per scenario			Existing network (IFRC)	
Maximum number of products per day	10 000	100 000	free	100 000	500 000
Equivalence in m^3	$30m^3$	$300m^3$		$300m^3$	$1\,500m^3$
Total Real Costs (without stock-outs, in €)	5,23E10€	1,32E11€	9,54E09€	2,84E09€	4,2E09€
Percentage of scenarios with stock-outs	26%	9%	0%	21%	10,3%
Amount of stock-out (nb products late x nb days waiting)	1,23E09	7,43E08	0	11,36E08	7,75E08
Mean number of warehouses used	9	4	1,6	3	3

13.5 Reliability and sensitivity analysis

13.5.1 List of resources to pre-position

These results contain no major surprises. If we consider only 6 products rather than 8, the costs of the response decrease. The scenarios that result in stock-out when we consider 8 products also present stock-out with only 6 products. Indeed, stock-outs are for large-scale disasters impacting millions of people, so way above the average number of affected per crisis.

In terms of location, though, only 57% of the scenarios exhibit the same optimal locations when we change the number of resources to preposition. Indeed, by modifying the list of resources, the list of suppliers is also modified, as are their locations. Upstream delivery costs are therefore changed.

In addition, by decreasing the number of resources, there are fewer products to deliver. Delivery, purchase and variable costs decrease proportionally, but the fixed costs do not. As a consequence, these fixed costs assume a larger proportion of the total cost of the response, especially in the case of small crises. According to the model, with fewer resources to deliver, stock should be maintained in the Caribbean for crises affecting fewer than 5,000 individuals, whatever the region affected. This dependence on the amount of fixed costs is further analysed in section 13.5.4.

This analysis shows the high dependence of the network on the number and nature of products maintained in the warehouses. Regarding the choice of the products that should be stored in warehouses, particular care was taken to include a dependence both between products

and regions, (to avoid, for example, the shipment of winter tents to warm regions) and between products and disasters, (to avoid for example, the shipment of malaria treatments in response Australian wildfires). This work was limited, however, to the initial list provided by the IFRC. Other possibilities, such as the storage of diggers in earthquake-prone areas, were not considered but would certainly be required in many cases.

13.5.2 Sensitivity from one year to another and impact of future demand

Over the three last years, the locations of crises have not altered significantly. The optimal locations chosen to respond to these crises have been similarly stable (see 13.10 on the next page).

Figure 13.10 on the facing page illustrates the locations of crisis and warehouses chosen with IFRC actual suppliers and no constraint on the number of warehouses. The same stability over the years is observed when we look at the results with local suppliers and when we limit the number of warehouses.

Looking now at perceived changes in future demand, we have seen evidence in chapter 11 on page 103 that a trend toward more disasters is foreseen in East Asia, South-East Asia and South-Central Asia. This increase is especially true for small and medium-sized hydrological disasters.

Our scenario approach allows an evaluation of the network design that is best suited to each of those cases. According to the model,

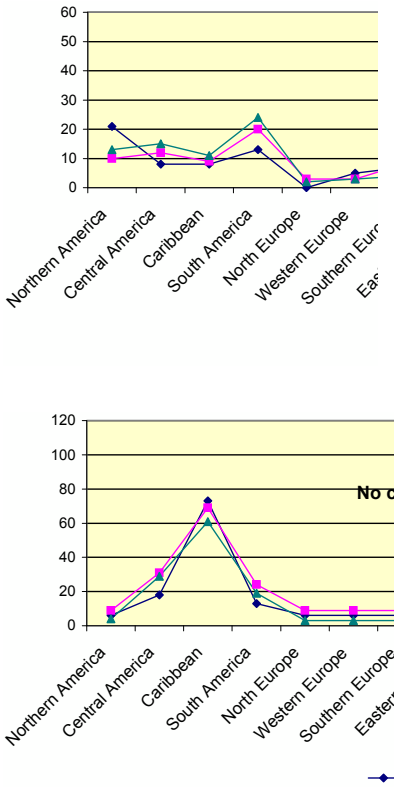
- For crises occurring in Eastern Asia affecting fewer than 100,000 individuals the best location is South-Central Asia. For crises involving up to 2,000,000 individuals, a local warehouse in Eastern Asia is better. In cases where more than 2,000,000 individuals are affected, one warehouse is insufficient, and so one should be maintained in Eastern Asia, a second in South-Central Asia.

- Similar results are obtained for crises occurring in South-East Asia. For small crisis, affecting fewer than 20,000 individuals, a warehouse in South Central Asia is best. When up to 1,000,000 individuals are affected, a local warehouse becomes more efficient. In cases involving more than 1,000,000 individuals two warehouses are needed, in South-East Asia and South-Central Asia are respectively. Finally, for mega-disasters, warehouses in South-East Asia, South-Central Asia and Eastern Asia are employed by the model.

- With respect to disasters in South-Central Asia, a local warehouse is the most efficient in every case. One additional warehouse in Eastern Asia or South-Eastern Asia is nevertheless needed for disasters affecting more than 200,000 individuals.

In conclusion, if more small and medium crises occur in any of these three regions, which predictions seem to indicate, then a warehouse in South-Central Asia would clearly be recommended.

Figure 13.10: Evolution of crisis locations and warehouse optimal locations to respond to last year crisis, sorted by year
Axe y : number of scenarios for which the location is optimal ; Axe x : potential location of warehouses



13.5.3 Returning to the relative proportions of costs

The contribution of each cost element of the objective function is roughly equivalent in various cases. The sum of transportation costs is always higher than other contributions. Delivery costs are lower in the case of optimized networks, both for additional warehouses and for relocated warehouses (see figure 13.11). This is explained by the fact that the computer model takes the location of suppliers into account, to propose the optimum locations. Indeed, when the possibility of local supply is added, delivery costs from suppliers to warehouses decrease.

As for the low proportion of emergency deliveries by air, this is true for those scenarios where sufficient stock is maintained in warehouses to rescue 25,000 families, (the targeted value at 15 days), and thus enabling the use of cheaper modes of delivery. The proportion changes as the level of service is increased for the immediate response.

Furthermore, the impact of the 20 biggest disasters on total annual costs is huge. This also explains why the delivery costs by plane are so small compared to deliveries by boat. With millions of affected to rescue in two months, so by boat, the proportion of the costs of early response, by plane, seem low. This is not the case anymore if we limit the total number of affected to be rescued by one organization (see figure 13.12 on the following page).

Figure 13.11: Cost contributions
CPU refers to urgent deliveries by planes, from suppliers to warehouses (upstream)
CPD refers to urgent deliveries by planes, from warehouses to beneficiaries (downstream)
CBU refers to deliveries by cheaper but slower means, like boats, from suppliers to warehouses
CBD refers to deliveries by cheaper but slower means, like boats, from warehouses to beneficiaries

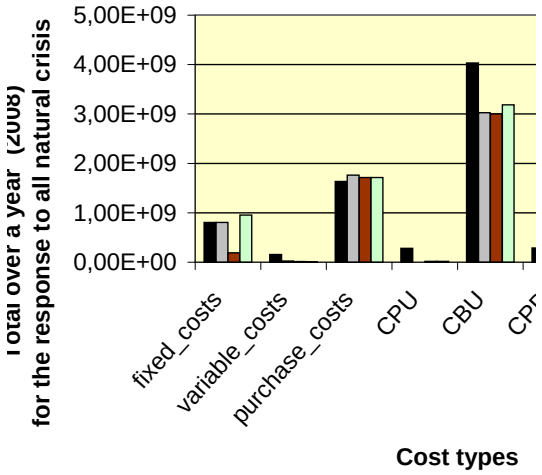
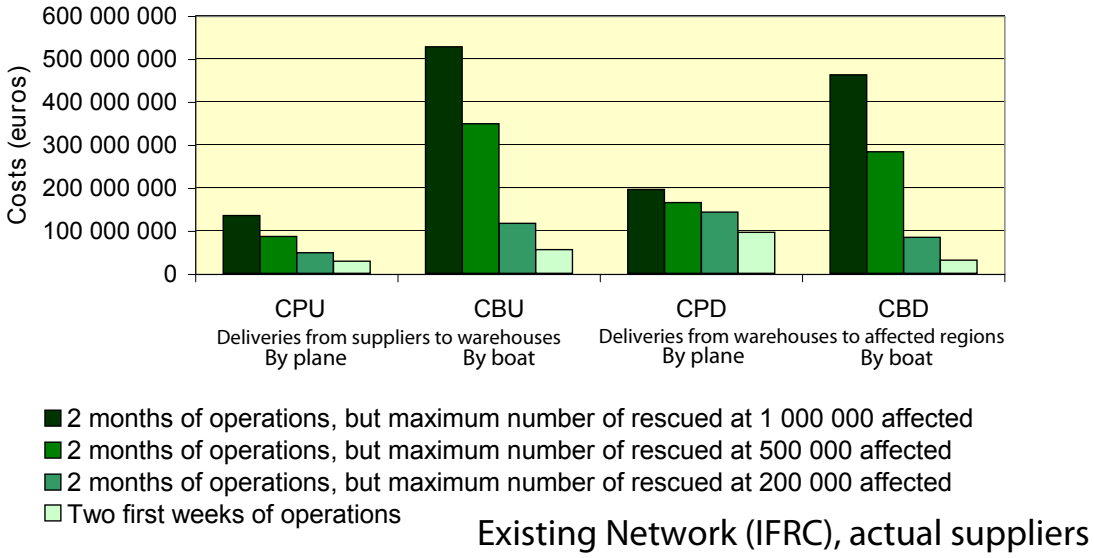


Figure 13.12: Delivery cost when we look at the first days of operations or when we limit the range of operations



13.5.4 Fixed Costs

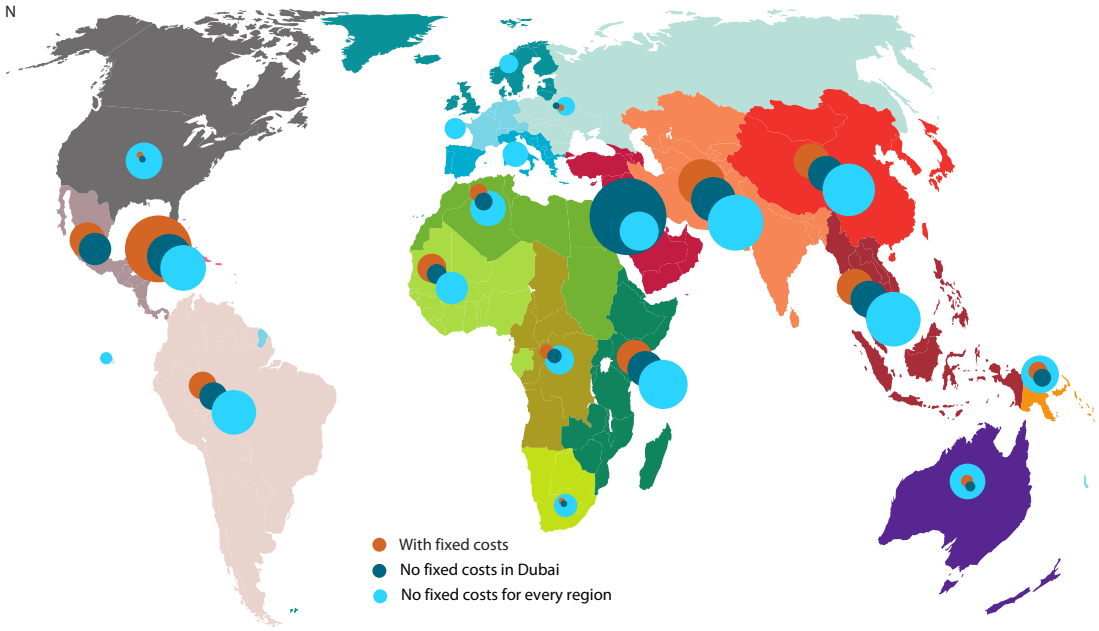
Looking now at the impact of changes in fixed costs upon the outcome of the model, Figure 13.13 on the next page provides an overview of the variations induced by these modifications. As the Map indicates, the geographical repartition is more homogeneous. This is due to the fact that, with lower fixed costs, more warehouses are opened in each of the scenarios. Indeed, the presence of fixed costs makes many of these warehouses more expensive, so that the programme centralises the network in few, cheaper places.

Other features to examine are the influences that agreements held with specific countries exerts upon the choices of warehouse locations. While an exhaustive study for every region is impossible because of time constraints, it is nevertheless worthwhile to examine two extreme situations.

Firstly, the impact of the presence of Dubai's free zone. Western Asia is not, in fact, a good location for a warehouse, unless their special agreements - which attract many humanitarian organizations – are taken into account. Figure 13.13 clearly shows that if the fixed costs associated with warehouse management can be reduced, then Dubai becomes a much better option that other regions in which to locate a warehouse.

On the other hand, if we consider the Caribbean, then should the standard of living (and thus the costs linked to maintaining a warehouse) increase here, then this region looses its attractiveness in favour of both Central America and Western Africa.

Figure 13.13: Sensitivity analysis on fixed costs
173 runs corresponding to the natural crisis of year 2008



13.5.5 Stock-out cost

The breaking point, where the model chooses to deliver products over stock-out, is achieved for a stock-out cost between 300 and 600€. (see table 13.6 on the next page) With IFRC specifications, and thus adequate contingency stock in the warehouse to assist 15,000 families within 2 weeks, there is no stock-out in the first days of operations, even with a stock-out cost chosen at 300€. With a stock-out cost at 300€, the only stock-outs are for the largest disasters, and here again, stock-out appears only at the end of operations. As for the geographical location, this mainly concerns Asian regions and East Africa, but this is more because of the intensity of the disaster than its geographical location, as other crises of small to medium size are catered for without difficulty.

Table 13.6: Impact of changes on stock-out costs

Cost of stockout (for each product one day late)	100	300	600	1000
Total Real Costs (€)	9,50E+09	9,51E+09	9,54E+09	9,54E+09
Percentage of scenarios with stockouts	21%	20%	0%	0%
Amount of stockout (nb products late x nb days waiting)	25 435 883	25 426 981	0	0

13.5.6 Impact of the level of service on costs

Responding to more affected within same time frames (5 and 15 days)

Once again as expected, with sufficient contingency stock in the warehouses to assist 15,000 families within 2 weeks and no constraint on the number of warehouses to open, for an optimal network redesigned for each scenario, there is no stock-out in the first days of operations, even if we double the target number of victims requiring rescue within two weeks. The average number of warehouses needs to increase slightly, however, from 1,6 to 2,2 warehouses per scenario, together with costs (though only by 2,2%).

When we limit the number of warehouses and look at how the three RLUs[7] could manage a higher demand in the first days of operations, the impact is much more important. First, the number of scenarios with stock-out increases from 3% to 11%. Secondly, the use of air-planes becomes massive. As a result, the costs to aid a limited number of affected during the first days (3,5% of the average demand for the 50 biggest disasters) is higher than 10% of the total costs just for these first 5 days.

Closing operations earlier or later

Closing the operations later has no impact on costs, as 50 days are sufficient to utilise boat transportation. Crises with no stock-outs in 50 days obviously have no stock-out in 60 and 70 days either. Furthermore, crises with stock-out in 50 days also have stock-out in 60 days, as the products that are not delivered on time are only required for the first days of the operations.

Table 13.7: Impact of changes on the targeted end of operations - optimal locations per scenario

	Optimal network per scenario			Existing network (IFRC)	
Targeted end of operations	20 days	30days	50 days	20 days	50 days
Total Real Costs (€)	9,71E+09€	9,543E+09€	9,542E+09€	11,72€+09€	11,26E+09€
Percentage of scenarios with stock-outs	0%	0%	0%	3%	3%
Amount of stock-out (nb products late x nb days waiting)	0	0	0	878 605	878 605

[7] IFRC Regional Logistics Units

As for closing operations earlier, in terms of immediate response, there is no impact on the level of service, as 30 or even 20 days are enough to deliver products by air. Costs are impacted, however, as more expensive methods of transportation are needed to rescue the targeted population more quickly (see table 13.7 on the facing page).

The fact that warehouses are able to manage the whole operations in 20 days for most of the disasters may seem surprising. This is nevertheless normal here because we did not limit the delivery capacity of warehouses. The analysis with a limited delivery capacity is done section 13.4 on page 138.

Responding quicker

If we intend responding to the same number of victims, but within 3 and 10 days instead of 5 and 15, the impact is not only visible in terms of costs, but also in the locations chosen. Indeed, as the required levels of service increase, the model opens warehouses that are progressively closer to crisis locations. This increases the costs, as these locations are not always the cheapest. Furthermore, air-transportation is generally essential when the time-frame within which aid can be delivered is reduced.

Total real costs for an increased reactivity are 1,6% times higher. Stock-out costs are also higher. When the program is allowed to choose both the number and locations of the warehouses, one out of eight scenarios will have stock-outs if the desired level of reactivity is increased (see table 13.8)

A closer look at the scenarios with stock-outs involving a higher reactivity shows that this additional stock-out is only for the third day. It also occurs only for scenarios in which two or more disasters are happening at the same time, and each of these scenarios has two or more warehouses running at the same time. After the third day, except in the case of mega-disasters, the levels of service targets can be met.

As for locations chosen on the basis of faster responses, South-Central Asia and South-East Asia should definitely host a warehouse. Warehouses in the Caribbean, Eastern Africa and Eastern Asia are also amongst those most frequently used.

Table 13.8: Impact of changes on level of service for immediate response

	Optimal network per scenario		Existing network (IFRC)		
Level of service for immediate response	3 and 10 days	5 and 15 days	3 and 10 days	4 and 10 days	5 and 15 days
Total Real Costs (€)	9,70E+09€	9,54E+09€	11,40E09€	11,36E+09€	11,26+09€
Percentage of scenarios with stock-outs	13%	0%	75%	3%	3%
Amount of stock-out (nb products late x nb days waiting)	1 567 344	0	17 667 800	878 605	878 605

13.6 Management summary

Figure 13.14 provides an overview of the key elements detailed in this chapter. The impact of strategic decisions with regards to the supply strategy, the local agreements or the choice of the targeted level of service is summarized.

Figure 13.15 on the next page illustrates the locations, which could be considered as optimal according to our analysis. Bigger circles correspond to a higher utilization rate.

Figure 13.14: Summary of results

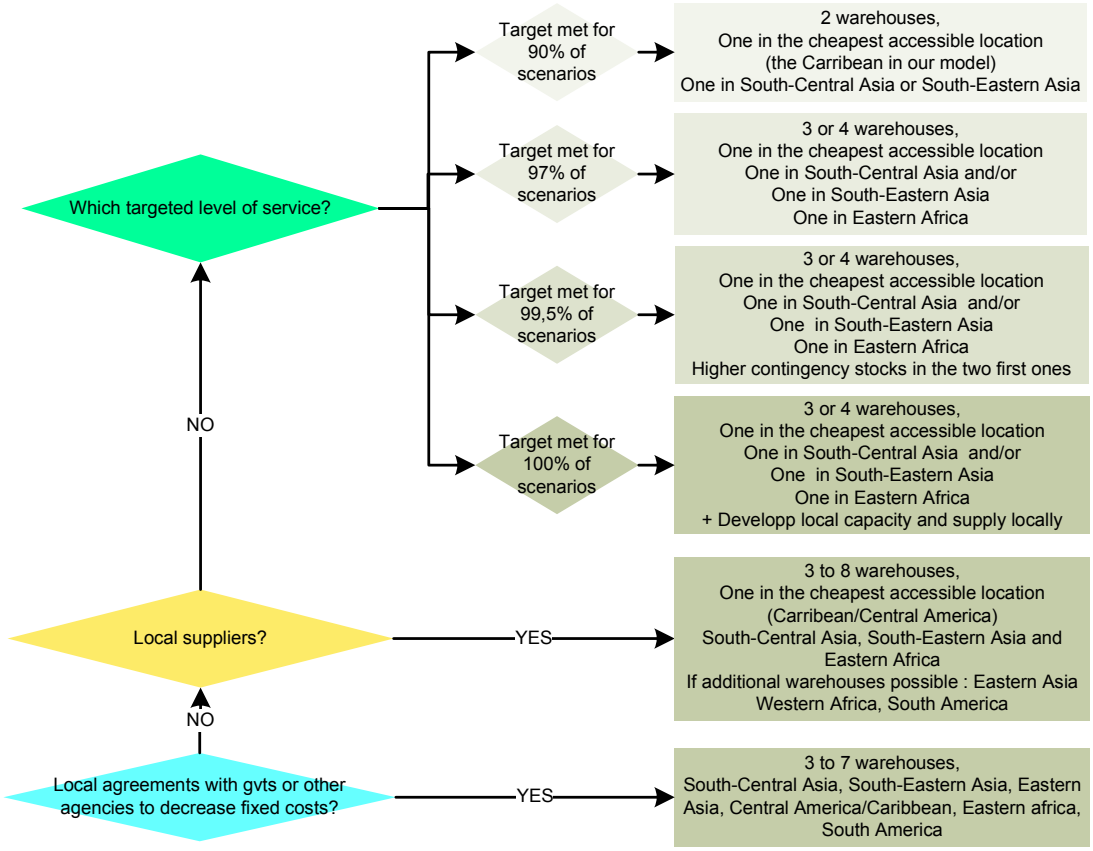
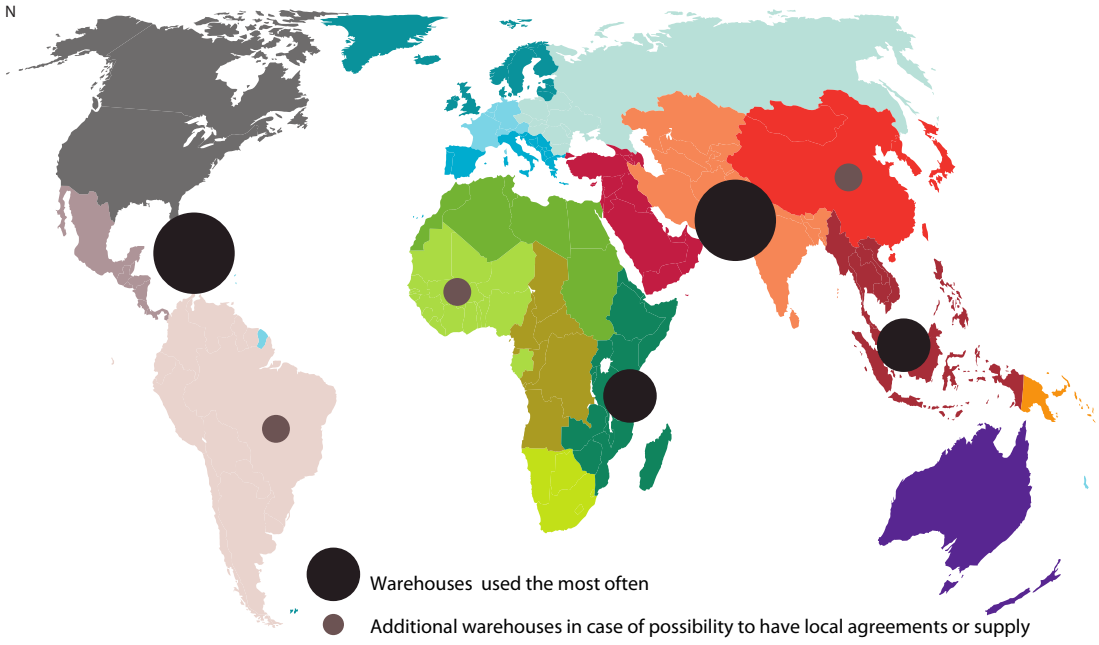


Figure 13.15: Overall view of optimal locations



14

Choice of the country within the region

14.1 Taking into account field realities

The previous chapter provided practical answers on which regions should have a warehouse depending on various choices, from the size of the contingency stock to the desired level of responsiveness and effectiveness.

The regions were chosen on the basis of the cheapest spot which facilitated the rescue of the targeted number of affected in the given time-frames. By doing this, we overlooked many elements that are also important for the choice of location. Safety, telecommunication infrastructure and many other criteria should also be taken into consideration for the design of the network, especially in the case of humanitarian supply networks, where people in need of relief items may be in warring or barely accessible areas. Yet as these elements vary widely within a single region, it was not possible to include them in the previous model.

This chapter will therefore focus on the local positioning of warehouses using a multi-criteria decision analysis (MCDA).

14.2 Choosing the approach

Over the last 50 years, many approaches to help decisions have been developed. They may be classified as follows [FGE05]:

1. Outranking methods ("French school")
2. Multi-attribute utility and value theories ("American school")
3. Fuzzy set approaches
4. Multi-Objective Mathematical Programming

14.2.1 Out Ranking Methods

Outranking methods regroup all methods that are based on a pair-based comparison of actions. Outranking indicates the degree of dominance of one alternative over another [RB98]. The two main examples are ELECTRE and PROMETHEE. For these methods, all the possible choices are listed, and then all of the participants compare them two by two. For each pair compared and each decision criterion, each participant says which one of the two possibilities is the best. The participant expresses his decision in terms of preference (weak or strong) or indifference. For the ELECTRE method, an alternative may also be vetoed. To decide if an alternative is better than another, an outranking relation is built using the values provided by the participants on the one hand, and on the other hand, the relative importance of each criterion. To validate the assertion that an alternative is better than another, two conditions must be fulfilled. First, "a sufficient majority of criteria should be in favour of this assertion". This is called the concordance condition. Secondly, "when the concordance condition holds, none of the criteria in the minority should oppose too strongly to the assertion".

The results are then analysed differently depending on the problem addressed. Choosing, ranking or sorting the alternatives is thus possible.

The results are then analysed differently depending on the problem addressed. Choosing, ranking or sorting the alternatives is thus possible.

14.2.2 Multi Attribute Utility and Value Theories

In these approaches, the choice among various actions is made on the basis of its utility, the utility being a real number representing the preferability of the considered action. Two major methods are AHP (Analytic Hierarchy Process) and MACBETH (Measuring Attractiveness by a Categorical Based Evaluation TecHnique).

According to its creator, Saaty, the AHP is "a theory of relative measurement on absolute scales of both tangible and intangible criteria based both on the judgement of knowledgeable and expert people and on existing measurements and statistics needed to make a decision" [FGE05]. This method uses also comparative judgement.

According to Costa, MACBETH is an approach "designed to build a quantitative model of values, developed in a way that enables facilitators to avoid forcing decision makers to produce direct numerical representations of their preferences." Participants answer a list of questions, providing a qualitative judgement about the difference in attractiveness of two stimuli. The MACBETH method then verifies the consistency of the participant's answers, and generates a numerical scale that is representative of the decision maker's judgments [CC04].

14.2.3 Fuzzy set approach

According to Zimmerman, a classical set "is normally defined as a collection of elements or objects $x \in X$ that can be finite, countable or overcountable. Each element can either belong to or not belong to a set A, $A \subseteq X$." In this case, the statement "x belongs to A" is either true or false. For a fuzzy set, on the contrary, "the characteristic function allows various degrees of membership for the elements of a given set" [Zim01].

Fuzzy set methods are therefore used especially when "decision problems take place in a complex environment where conflicting systems of logic, uncertain and imprecise knowledge, and possibly vague preferences have to be considered". [FGE05]

14.2.4 Multi-objective mathematical programming

Mathematical programming is used here to provide an optimum solution to a problem having two or more objectives. The methods used to solve the problem usually deal with a priori weighted sums of the objective functions. Other methods exist, which use sequential explorations of solutions, for example [Ben+71].

Roy distinguishes four different classes of approaches [Roy71]:

- Aggregation of multiple objective functions into a unique function defining a complete preference order
- Progressive definition of preference together with exploration of the feasible set
- Definition of a partial order stronger than the product of the n complete orders associated with the n objective functions
- Maximum reduction of uncertainty and incomparability

According to Marler, "the selection of a specific method depends on the type of information that is provided in the problem, the user's preferences, the solution requirements, and the availability of software" [MA04].

14.2.5 Our approach : mathematical programming with an aggregating approach

Outranking methods facilitate choosing an alternative when there are many criteria and many participants in the decision process. These methods are therefore typically used for group decision-making situations [KKP01], which is not really our case. Furthermore, this approach "might become very expensive (computationally speaking) when there is a large number of alternatives" [Coe00]. In our case, we have more than 220 countries, which would require 25,000 rankings. And even if the ranking was limited to the best locations as defined by our regional analysis, then we would still have more than 500 comparisons just to study South-Central Asia, Eastern Africa and the Caribbean.

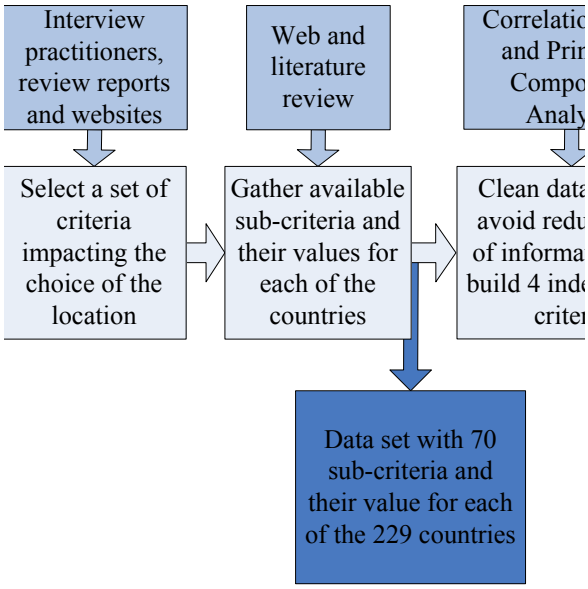
The difficulty of interpretation of the results is also often listed among the main drawbacks of outranking methods [KKP01]. Moreover, according to Kangas, "the techniques by which the preference information is dealt with in calculations are rather complicated and hard to explain to nonspecialists" [KKP01].

As for the main method used in MAUT, AHP, according to Salomon, one of its major limitations is "the necessary independence among elements from a hierarchical level" [SM01]. As our data set is full of interrelated criteria, this method would be difficult to use as such. Furthermore, AHP also compares pairs, an option that we already set aside.

Regarding the use of MACBETH, it is not justified here as numerous databases are available to provide a numerical value of each criterion for each country.

Concerning the use of the fuzzy set approach, once again, there are quantitative criteria available for ranking countries. The percentage of paved roads, the number of ports and airports or annual cargo traffic are available quantitative data, for example. Though we agree that some of these values may evolve over time, especially in politically volatile countries, and

Figure 14.1: Our approach for choosing the best location for opening a warehouse



would therefore justify the use of such approaches, we chose to provide here a clear vision of the current situation, which is currently lacking.

The location decision could then be validated using a complementary approach which would take into account the various kinds of uncertainties (see section 2.7 on page 26) that may affect the results. This part is considered to be the natural research perspective of our study.

We therefore opted for an approach by multi-objective mathematical programming, which aggregates the criteria to provide a ranking of various countries. The next section details how we built a set of four independent criteria to establish a quantitative measurement of each of the decision criteria listed by humanitarians (accessibility, security, telecommunication networks and corruption/easy customs procedures).

Section 14.4 on page 155 will then explain how we aggregate these indicators using various weighting factors and how we avoid the selection of a country which does not satisfy a minimum level in one or more of the criteria. The results are then analysed in section 14.5 on page 159 and compared with the methods used by humanitarians when they chose their actual warehouse locations. An overview of our approach is illustrated by figure 14.1.

14.3 Selecting the criteria and gathering data

A study of internal and external documentation as well as interviews with humanitarians has enabled us to list the parameters which should be taken into account in choosing a relevant location or locations. Table 8.1 on page 85, and in general, section 8.1 on page 83, provide a detailed list of indicators used by the United Nations in choosing the location of their existing warehouses. Their approach used practitioners' local knowledge of the region to give a mark to the various locations on the basis of their attractiveness for each of the chosen parameters. While it is useful to draw on the knowledge and experience of field workers, the objectivity and therefore the reproducibility and robustness of this approach is questionable.

What we propose in this chapter is to use objective public data to help make the choice of the best location, then compare our results with the ones resulting from the ranking done by the UN.

We therefore built a database to put together available data on countries. Various sources, such as the CIA World Factbook, databases from the World Bank Group, Airports Council International or the Institute for Economics and Peace were used. We also looked at academic works, like reports from the Uppsala Conflict Data Program on peace agreements and conflict/war related deaths, and of course the EM-DAT from the Université Catholique de Louvain on disaster lists. Finally, we gathered data from NGO websites such as the data sets provided by the UNDP, the UNFPA and Transparency International.

With this work, we have 50 criteria objectively marked for each country, provided in appendices, with up to four available sources to allow cross-checking of the values. As this is a fairly broad database, especially knowing that most of it is interrelated, we reduced the data with a principal component analysis. We have them all normalised in order to facilitate the analyses. We also made sure than for each sub-criteria, the minimum score goes to the worst country, and vice versa. For example, for the sub criteria "number of civilian victims per inhabitants due to one-sided conflicts", our indicator is 100 minus the number of victims (once normalised).

Indeed, "the central idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables" [Jol02].

To provide a better understanding of the results, we sorted the data set into four main categories, which correspond to the elements outlined in our study :

- Data related to accessibility and infrastructure
- Data related to telecommunications networks
- Data related to the level of corruption and foreseeable customs difficulties
- Data related to safety and security

For each of these categories, we looked first at the contributions of each country, in order to set aside those having such a high contribution that it significantly changed the analyse. Indeed, according to Saporta, usually it is not desirable, especially for the first components, that an individual contributes excessively because this may cause instability. Removing this individual sharply changes the results of the analysis. This individual may still be added afterwards if the high level of contribution wasn't due to a typing error [Sap90]. For example, for the analysis of the corruption criteria, countries such as Liberia or Burkina Faso have been taken out.

Then, we looked at other basic elements, such as the contributions of the sub-criteria and their correlation. This enabled us to retain three to five sub-criteria for each main categories (accessibility, corruption, security, telecommunication). Table 14.1 illustrates the sub-criteria before and after this first selection for the sub-criteria linked with corruption. As you can see, there are 15 pairs correlated by more than 60%, with 6 by more than 80%. There is therefore no need to keep all these strongly correlated variables. On the contrary, neither the sub-criteria "perceived corruption index" nor "GDP per capita rank minus HDI rank" nor "political stability" are correlated with the others. They should therefore be kept for the analysis.

Figure 14.2: Principal Component Analysis for data related to corruption - Map before looking at correlations

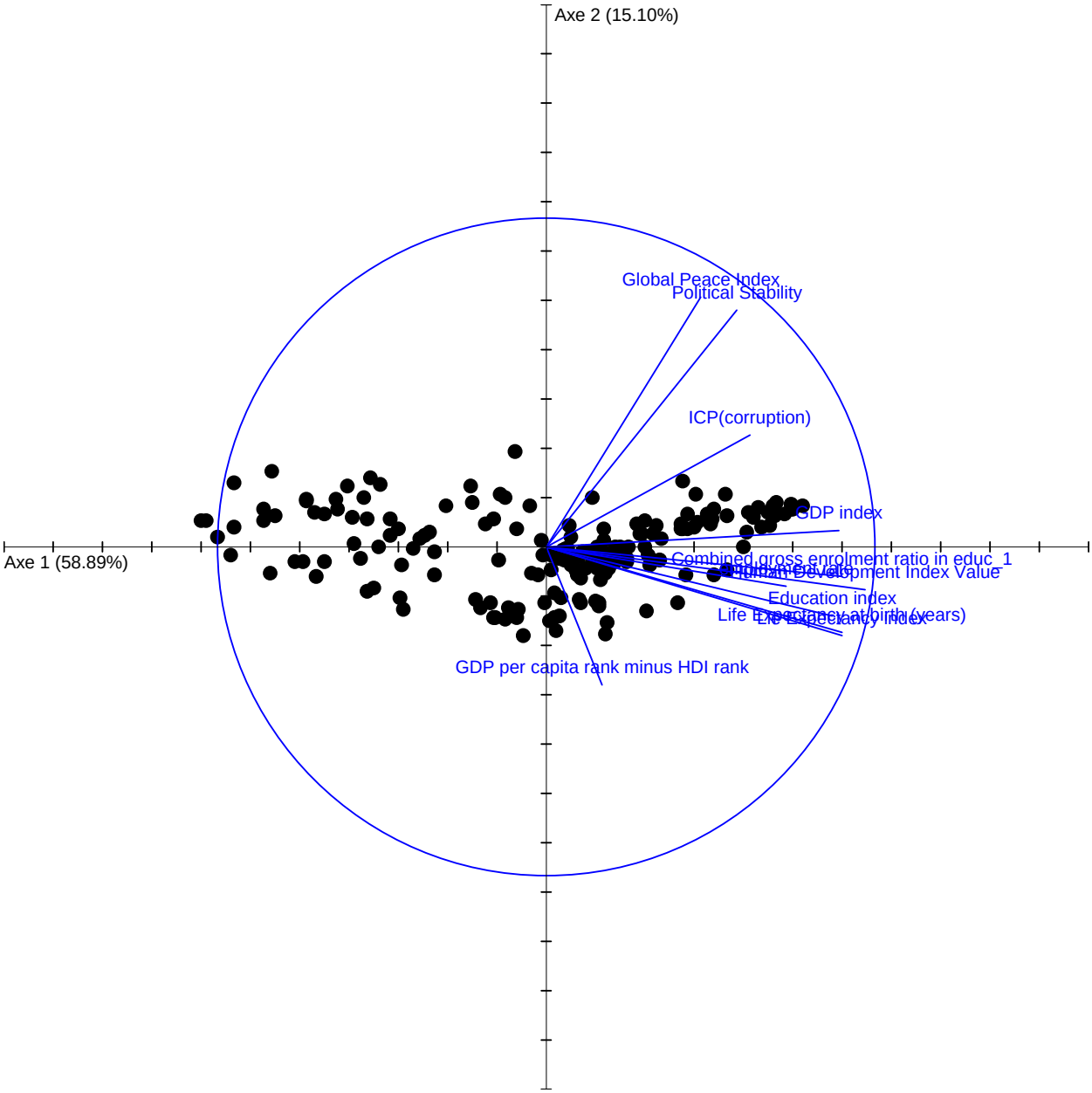


Table 14.1: Correlations table values (in %) for data related to corruption before reduction

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	Perceived corruption index	100									
C2	Human Development Index	54	100								
C3	Life expectancy at birth	48	91	100							
C4	Combined gross enrolment ratio in education	49	88	76	100						
C5	Education index	42	91	74	90	100					
C6	GDP index	55	93	76	78	77	100				
C7	GDP per capita rank minus HDI rank	1	13	26	24	24	-11	100			
C8	Employment rate	31	69	66	59	60	63	9	100		
C9	Political stability	54	45	34	46	36	50	-4	35	100	
C10	Global peace index	41	33	24	37	26	39	-2	26	86	100

Table 14.2: Contributions of sub-criteria to the construction of principal components (PC) for the corruption criteria

	f1	f2	f3	f4	f5
ICP(corruption)	23%	5%	22%	38%	12%
Human Development Index Value	31%	2%	7%	5%	55%
GDP per capita rank minus HDI rank	1%	80%	18%	1%	0%
Political Stability	22%	9%	16%	53%	1%
employment rate	23%	4%	38%	3%	32%

Figure 14.2 on the facing page is the PCA before our study of correlations. Figure 14.3 on the next page is the PCA after our study of correlations. As can be seen on this figure, 70% of the variance is represented by axes 1 and 2, which ensures a good representation.

From this point, if we wanted to reduce further the number of sub-criteria used, the next step would be to look at the contributions of each sub-criteria. If two sub-criteria have exactly the same contribution, we could remove one of them. Table 14.2 details the contributions of each sub-criteria, for corruption. In this case, once we remove the sub-criteria strongly correlated with others, we obtain five sub-criteria. Four of them have a similar contribution : the perceived corruption index, the human development index, the political stability and the global peace index.

As five sub-criteria are not too big a number, we will keep them all for our analysis.

The process for each of the three other indicators (corruption, security, accessibility) is exactly the same. Figures 14.4, 14.6 and 14.5 illustrate the maps obtained after cleaning the data sets.

14.4 Aggregating the parameters

For the security indicator, according to the PCA, three sub-criteria are kept: the number of one-sided[1] acts of violence over 20 years, the political stability of the country and the total number of affected per natural crisis per number of inhabitants. Indeed, first of all, it would not be pertinent to set up in a warring country with relief items targeted for natural disaster

[1] Intentional attacks on civilians by governments and formally organized armed groups

Figure 14.3: Principal Component Analysis for data related to corruption - Map

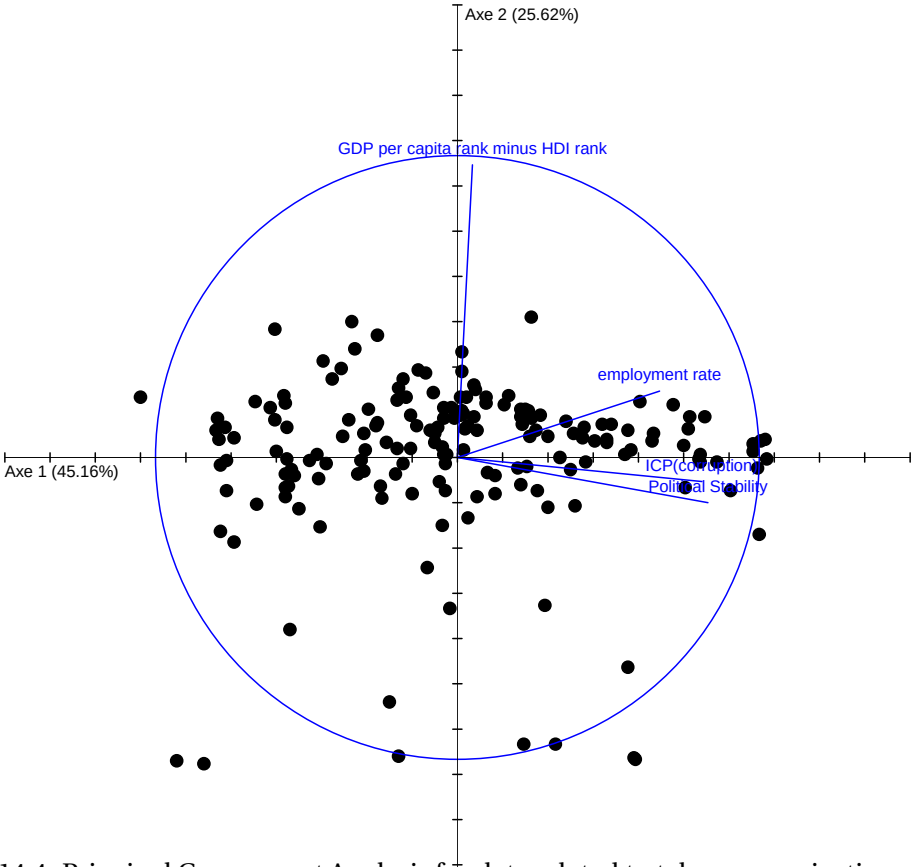


Figure 14.4: Principal Component Analysis for data related to telecommunications - Map

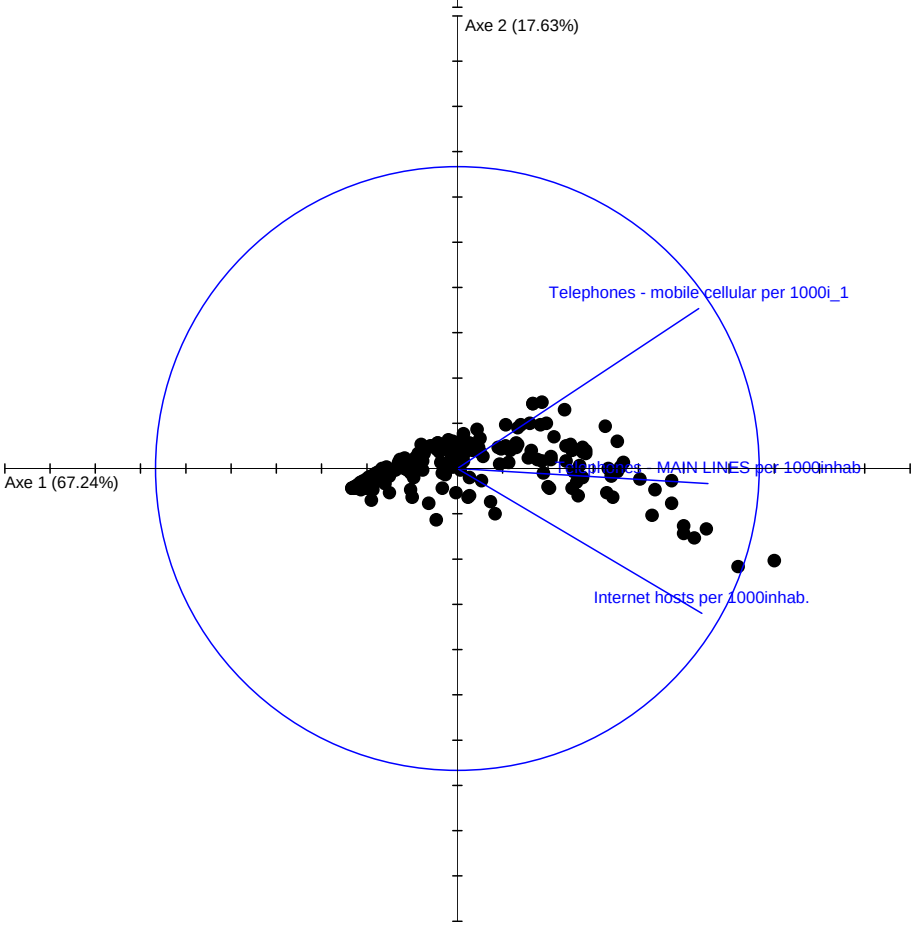


Figure 14.5: Principal Component Analysis for data related to security - Map

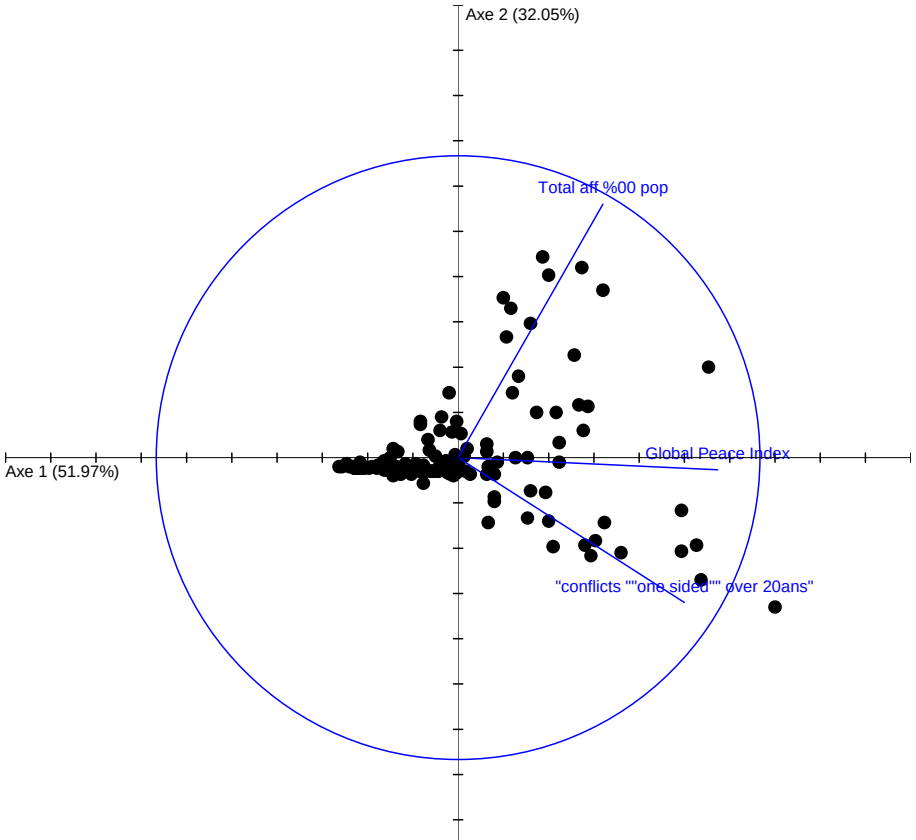
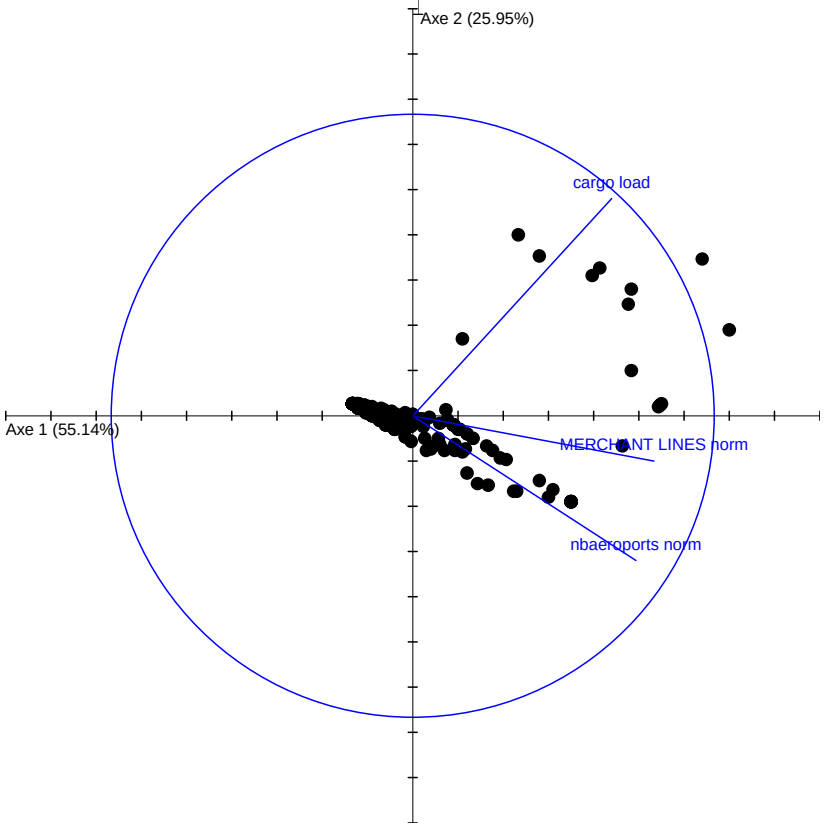


Figure 14.6: Principal Component Analysis for data related to accessibility - Map



victims. Secondly, though it is vital to avoid areas where hostages and other civilians may be killed, it is also necessary to build a warehouse in an area where it will not collapse because of a natural disaster.

Other sub-criteria, such as the number of crises, the total number of affected per natural disasters (but not divided by the number of inhabitants) or the civilians killed over 5 years were initially in the dataset. They were closely related to the sub-criteria we kept.

For the telecommunications indicator, out of the 11 sub-criteria, many were correlated. The numbers of main lines in use and the number of Internet users were strongly correlated, as were the number of subscriptions to mobile phones and the number of Internet users per total inhabitants for example. As for the accessibility indicator, as expected, the number of parts and terminal and the number of airports were correlated. We therefore kept only the number of airports. As for the presence of the country in the ranking of the top international airports, it was strongly correlated with the cargo load (nearly 90%).

The list of all these sub-criteria, before and after the analysis, is in appendix

The construction of the four criteria (accessibility, telecommunication, corruption, security) was done by using the principal components as defined by the PCA[2]. For each of our criteria, as more than 70% of the variance is expressed by the first two axes, we have taken only these two components into account. Each component is weighted by the variances it expresses. If we come back to the first example, the corruption criteria, then the formula for aggregating all the sub-criteria is as follows:

$$
\begin{aligned}
(0,45+0,26) \times \text{Corruption} = \quad & 0,45 \times \begin{cases} 0,23 \times \text{Perceived corruption index} \\ +\ 0,31 \times \text{Human development index} \\ +\ 0,01 \times \text{GDP per capita rank minus HDI rank} \\ +\ 0,22 \times \text{Political stability} \\ +\ 0,23 \times \text{Employment rate} \end{cases} \\
& + 0,26 \times \begin{cases} 0,05 \times \text{Perceived corruption index} \\ +\ 0,02 \times \text{Human development index} \\ +\ 0,80 \times \text{GDP per capita rank minus HDI rank} \\ +\ 0,09 \times \text{Political stability} + \ 0,04 \times \text{Employment rate} \end{cases}
\end{aligned}
\tag{14.1}
$$

The corruption criteria can therefore be calculated with the following formula:

$$
\text{Corruption} = \begin{cases} 0,16 \times \text{Perceived corruption index} \\ +\ 0,20 \times \text{Human development index} \\ +\ 0,30 \times \text{GDP per capita rank minus HDI rank} \\ +\ 0,17 \times \text{Political stability} \\ +\ 0,16 \times \text{Employment rate} \end{cases}
\tag{14.2}
$$

Similarly, for the three others, we have :

[2] Principal Component Analysis

$$\text{Security} = \begin{cases} 0,32 \times \text{Number of victims of conflicts "one-sided" over 20 years per inhabitant} \\ + 0,30 \times \text{Global peace index} \\ + 0,38 \times \text{Annual number of affected per natural crisis per inhabitant} \end{cases} \tag{14.3}$$

$$\text{Accessibility} = \begin{cases} 0,33 \times \text{Number of airports} \\ + 0,27 \times \text{Merchant lines} \\ + 0,40 \times \text{Annual cargo load} \end{cases} \tag{14.4}$$

$$\text{Telecommunications} = \begin{cases} 0,28 \times \text{Telephone main lines per inhabitants} \\ + 0,36 \times \text{Telephone mobile cellular per inhabitants} \\ + 0,36 \times \text{Internet hosts per inhabitants} \end{cases} \tag{14.5}$$

To rank the countries on the basis of these four indicators, a short linear programme was written to help make the decision.

First, some countries which do not meet a minimum level in one of the indicators should not be considered. Indeed, nobody would willingly maintain stock in a warring country, for example, even if it apparently had satisfactory infrastructure and telecommunication facilities. The programme therefore makes sure that the overall score for such countries is null.

In addition , there is a level of uncertainty on the weighting factors applied to each of the indicators. For some humanitarians, security comes first while others put more importance on infrastructure and accessibility. We therefore used five sets of weights: one with equal importance to each indicator, and then four with progressively more weight on one of the indicators. Table 14.3 on the following page summarises the global results and specifies whether the country has the same rank for each set of weights or if the weighting factor has an impact on the ranking.

14.5 Analysis and comparison with other methods

Some details regarding the choice of the Asian depot as documented by the United Nations can be found in table 14.4 on page 161.

Table 14.5 provides our scores for each of the countries selected by the UN.

Table 14.3: "Best" countries per regions

The figures in bracket represent the differences depending on the weighting factors applied. For example (4 1 0) means that the country is ranked first most of the cases. There is nevertheless one set of weighting factors, with which another country out ranked it.

Region	Best choice	Second best choice	Third possibility
Australia and New Zeland	Australia (5 0 0)	New Zealand (0 5 0)	null
Caribbean	Trinidad and Tobago (4 0 0)	Barbados (0 2 2)	Bahamas (1 1 2)
Central America	Mexico (5 0 0)	Panama (0 5 0)	Costa Rica (0 0 4)
Eastern Africa	Mauritius (5 0 0)	Seychelles (0 3 1)	Zambia (0 1 2)
Eastern Asia	Japan (5 0 0)	Taiwan (0 3 2)	Hong Kong (China) (0 1 2)
Eastern Europe	Poland (4 0 1)	Bulgaria (1 3 1)	Slovakia (0 0 3)
Melanesia	Papua New Guinea (4 0 1)	New Caledonia (1 3 0)	Fiji (0 2 3)
Micronesia	Kiribati (3 2 0)	Marshall Is (1 3 1)	Guam (1 0 4)
Middle Africa	Equatorial Guinea (3 2 0)	Cameroon (2 3 0)	Central African Rep (0 0 5)
North Europe	United Kingdom (4 1 0)	Sweden (1 4 0)	Norway (0 0 3)
Northern Africa	Egypt (4 0 1)	Morocco (0 4 1)	Tunisia (1 1 3)
Northern America	United States (4 1 0)	Canada (1 4 0)	Bermuda (0 0 4)
Polynesia	Cook Islands (4 1 0)	Tonga (1 3 0)	Samoa (0 1 3)
South America	Brazil (5 0 0)	Argentina (0 3 1)	Uruguay (0 2 2)
South-central Asia	India (4 1 0)	Kazakhstan (1 4 0)	Uzbekistan (0 0 5)
South-eastern Asia	Singapore (5 0 0)	Malaysia (0 5 0)	Indonesia (0 0 3)
Southern Africa	Botswana (4 1 0)	South Africa (1 3 1)	Namibia (0 1 4)
Southern Europe	Italy (5 0 0)	Greece (0 5 0)	Spain (0 0 3)
Western Africa	Gabon (4 1 0)	Ghana (1 4 0)	Cape Verde Is (0 0 3)
Western Asia	Cyprus (4 1 0)	United Arab Emirates (1 4 0)	Qatar (0 0 2)
Western Europe	France (3 2 0)	Germany (2 3 0)	Netherlands (0 0 5)

Table 14.4: Comparative Analysis of Potential Sites in SE Asia, from [RPB08]

Criteria/Indicators	Max Score	Thailand Utapao	Cambodia Phnom Penh	Singapore Singapore	Malaysia Subang	Indonesia Batam
Strategic location and geopolitical situation	10	7	4	10	9	4
2) Level of commitment and long-term sustainability	10	7	6	8	9	5
3) Storage, office and training facilities	15	11	10	12	14	6
4) Proximity to roads and railway network	10	6	4	9	9	3
5) Airport	10	8	6	9	9	7
6) Proximity to sea port	5	3	2	5	5	3
7) Air National Carriers	5	4	2	4	4	4
8) Technical services available	5	4	3	5	5	3
9) Access to military assets	5	5	1	5	5	3
10) Access to national and international markets	5	5	2	4	5	3
11) Telecom network	5	4	2	5	5	4
12) Customs procedures	5	4	4	4	4	3
13) Financial system	5	4	2	5	5	3
14) Immunities and privileges to premises and UN Staff	5	5	4	5	5	4
TOTAL	100	76	52	89	91	55

Table 14.5: Our scores for the countries selected by the UN

Weights	Countries Thailand	Cambodia	Singapore	Malaysia	Indonesia
All equally weighed	197	97	315	286	198
Telecom	220	101	377	313	208
Accessibility	277	126	384	376	241
Corruption	268	158	406	365	272
Security	220	100	408	376	269

As we can see in table 14.5, though Singapore came first in every cases, the mark of Malaysia is not much lower. Indonesia comes next on the list, closely followed by Thailand. This, for example, seems to be in line with some of the IFRC's questions about their Kuala Lumpur RLU[3]. While Kuala Lumpur seemed a good option, an internal report suggested that Singapore might be a better option. Our ranking confirms this internal analysis, as Indonesia comes only third in the ranking of South-Eastern Asian countries.

A comparison between tables 14.4 and 14.5 shows that our approach provides close results. In both rankings, Singapore and Malaysia are considered good options (though not in the same relative place). The UN method ranked Thailand third, which differs from our ranking, in which Thailand is fourth because its level of security and telecommunication are fairly low, though still better than Cambodia.

[3] Regional Logistics Unit

As for South-Central Asia, which was the region chosen by our program to respond to most of the medium and big disasters, the local analysis would recommend the opening of a warehouse in India, especially when accessibility is given a prime importance.

If we now look at IFRC logistics network, then we see that all of the locations they chose are ranked within the first quarter of our ranking. They may still improve their logistics network by opening a new warehouse in Singapore or India. As for the RLU in Panama, it has a similar profile than the best country of the Caribbean. Indeed, if we look at the scores of the 234 countries, Panama and the Bahamas are 50 and 51st in our ranking. With local agreements with the government in Panama and many other organizations to collaborate with to decrease costs, then it is definitely a good option to keep the RLU in Panama. As for Dubai, if it comes only second (after Cyprus) in the list of the best countries of Western Asia, it is not by much either. None of their scores are further than 7% from one other. The case in which Cyprus loses top ranking to the United Arab Emirates is when accessibility is considered to be the most important indicator. In this specific case, the set of weighting factors has an impact in the ranking. If the warehouse positionned in Western Asia is to send relief to the most remote parts of Africa, then a high weight on accessibility is required. In this case, the choice for location made by the IFRC is justified.

This chapter has provided one way of choosing an adequate location based on local considerations. It complements the previous chapter by taking into account criteria such as the levels of security, corruption, accessibility and telecommunication. Of course, our initial data set is far from exhaustive and the resulting indicators only partially represent reality. Furthermore, the data available were not always up to date. For example, the number of victims of one-sided violence dates from 1980 to 2000, and so is already 10 years old. Since then, the rates of some countries may have evolved. This explains the ranking given to Kazakhstan, which in the past was much more peaceful than it is at the present time. Our main research perspectives on this local optimisation are both to use the expertise of practitioners to complement the study and to take into account the various kind of uncertainties of our data set.

Conclusion

Confronted with an increasing pressure to respond more effectively, more efficiently, and above all quicker than before, the humanitarian sector seeks ways to meet both affected and donors expectations. To deliver aid to those in need, organisations have to set up complex supply chains within a few days. All of this being under higher level of uncertainties than most of the commercial supply chains. Nobody could have foreseen the devastating impact of the Haiti earthquake for example. Nobody could even have foreseen its occurrence more than a few hours in advance. Same for the hurricane Nargis in Myanmar. Demand is unknown, before, but also after the disaster. The political instability and many other complexity factors force humanitarian organisations to work on their capacity to react quickly to changes. This capacity is fundamental for NGOs[4]. It is also becoming of prime importance in the private sector, where disruption risks, demand volatility and customers' expectations have increased drastically over the last years.

Given these considerations, specificities and needs of humanitarian supply chains have been analysed in the first part of this thesis. This study, based on case study research and literature review, outlined nine key elements, which are detailed in chapter 2. The dynamic of operations, the challenges due to the diversity in nature, number and incentives of stakeholders, the financing system or the complexity of their environment are among this list of specificities.

Our research objectives have then been motivated by a literature review. Three main elements have retained our attention:

1. Even if many research perspectives are listed in most of the existing literature, few are actually studied in depth.
2. Most of the articles use one or more methods without much consideration of their applicability in the context of relief aid.
3. If many lessons are given by academics to humanitarians, none seeks to make explicit and consolidate humanitarian experiences.

In this context, the aim of our research is to improve the design and the management of agile supply chain, especially in the context of relief aid. Defining and measuring the agility capability of supply chains is thus the main purpose of the second part of this thesis. Chapters 6 on page 63 and 7 on page 67 provide a list of best practices and metrics, which enable to assess the agility maturity level of a supply chain. Three key performance indicators are assessed: responsiveness, effectiveness and flexibility. Each of them is composed of of two to four sub-criteria, which all together are essential to ensure a high agility level.

[4] Non Governemental Organisations

Knowing that more than 30% of those metrics are directly linked with the design of the logistics network, the third part of this thesis focuses on this specific issue. Our objective was to look after the most efficient solutions, that enable to deliver aid within acceptable time frames.

To carry through this analysis, we have divided the work in three steps. First, we have looked at past disasters, their trends and forecasts to build realistic scenarios. Secondly, we have written a MIP[5] in order to choose the best locations, on a regional level, depending on various strategic choices. Chapter 13 on page 123 provide practical answers regarding the design of the logistics network with and without taking into account existing networks. It also analyses the sensitivity of the model to various data and parameters.

The main results of this chapter are that one central warehouse in a place, where local agreements with governments or other NGOs decrease fixed costs is the most efficient option both for small crisis and for really big disasters, to complement the local warehouse when it cannot meet the demand. As for medium size disasters, locations such as South-Central Asia, South-Eastern Asia and Eastern Africa are recommended. Depending on the targeted population, on the targeted level of service, on what is considered "acceptable" time frame, the answers with regards to the number, size and location of warehouses differ slightly. As the possibility to supply locally, it impacts costs and level of service, but not the locations chosen as optimal.

The third and final step of our network design is to choose the best location on a local basis. Indeed, according to humanitarian practitioners, the level of security, of corruption as well as infrastructures for telecommunication and accessibility are of prime importance. Quantitative values have been calculated for each country, for each criteria. A principal component analysis enabled us to build those four criteria from a database of more than 50 sub-criteria gathered with a review of the literature and the web.

From this study, we can conclude that a warehouse in Singapore or in India would be recommended.

This optimization answers a real need expressed by many humanitarian agencies. We focused our study on the IFRC[6]. Other organisations, such as the French Red Cross or World Vision International also confirmed the relevance of this research problem. Simulations for the UNHRN[7] and World Vision International are on-going.

This study has showed that the use of models and optimization-based decision-support systems can be used to provide a robust and impartial answer to questions such as "how do we ensure an adequate and swift response to disaster?" "where should we have advanced stock, and why?" which parameters impact the decision process?". Our study is a prototype, which can be improved in many ways. Indeed, we limited our study to most of the well-known issues faced by humanitarian organizations. Additional discussions with NGOs to validate our results and their applicability would be needed. Other ways of dealing with uncertainties can also be compared or added to our models. Indeed, our approach was to look at various questions and uncertainties and analysis their impact on the response. The use of fuzzy logic or any other approach to include the uncertainties within the model could complement our study. This is true for the location part, but it is also true for the overall assessment of agility.

[5] Mixed-Integer linear Program
[6] International Federation of the Red Cross and Red Crescent Societies
[7] the UN humanitarian response network

Résumé des travaux en français

Au cours de ces dix à quinze dernières années, le secteur humanitaire a beaucoup évolué. D'une part, la nature, la fréquence et l'importance des crises naturelles poussent les organisations humanitaires à gérer de plus en plus d'opérations en parallèle. D'autre part, les contraintes dues aux flux financiers restreints et aux exigences accrues des donateurs les poussent à davantage de professionnalisation et de rationalisation. C'est dans ce contexte de recherche de performance, de mesure et d'amélioration que se positionnent nos travaux.

En moyenne, chaque année, plus de 210 millions de personnes sont affectées par des catastrophes naturelles. Les organisations humanitaires doivent donc souvent mettre en place des chaînes logistiques complexes et ce dans un environnement excessivement volatile. Ces chaînes logistiques ont de nombreuses particularités qui les différencient de leurs homologues habituellement rencontrées dans l'industrie traditionnelle.

Une étude approfondie des chaînes logistiques humanitaires a donc été menée afin de bien appréhender leurs spécificités, leurs points forts et leurs faiblesses. C'est l'objet de la première partie de cette thèse. Un résultat important de notre travail porte ainsi sur la caractérisation formelle de ces chaînes logistiques. En nous appuyant sur une étude de cas présentée au chapitre 1, plusieurs discussions avec des membres d'ONG ainsi que sur une revue de la littérature, nous avons ciblé les principales caractéristiques des chaines logistique humanitaires, leur points forts et leurs faiblesses. Neuf points clés ont ainsi été retenus et détaillés dans le chapitre 2. La dynamique des opérations humanitaires, les challenges dus au nombre et à la nature des intervenants, au système de financement sont ainsi listés, de même que l'impact des médias, la courte durée des opérations ou encore l'objectif même des chaînes logistiques, mises en place pour sauver des vies, et non pour gagner de l'argent sont ainsi explicités. Deux des principaux problèmes que rencontrent les humanitaires sont également détaillés : les nombreuses incertitudes ainsi que les problèmes de coordinations auxquels ils sont confrontés.

Par une revue de la littérature, nous avons fait ressortir les principaux éléments à étudier, ceux qui l'ont déjà été ou sont en cours et ceux qui mériteraient d'être poussé plus avant. Trois éléments ont principalement retenu notre attention.

1. Même si de nombreux points sont soulevés, peu ont vraiment fait l'objet d'une étude détaillée.
2. La plupart des articles publiés appliquent un outil ou une méthode préexistante sans trop se soucier de son applicabilité dans le secteur humanitaire.
3. Enfin, si beaucoup de leçons sont données par les académiques aux humanitaires, peu d'articles cherchent à expliciter et consolider les expériences des humanitaires.

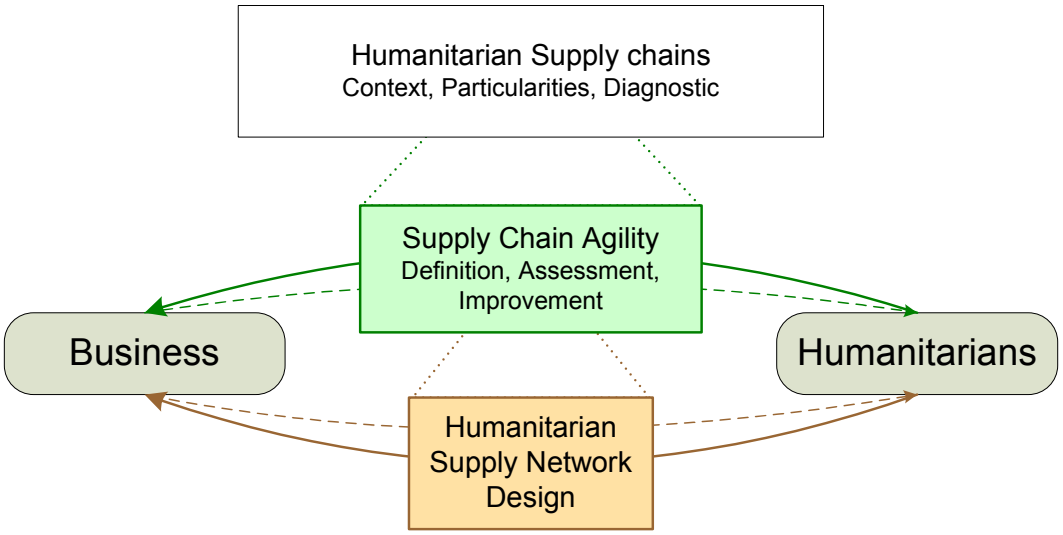


FIGURE 14.7: Research Objectives

Dans ce contexte, notre étude vise à expliciter, mesurer et améliorer l'une des principales caractéristiques des chaînes logistiques humanitaires : leur capacité à répondre rapidement et de manière adéquate aux changements à court terme. Ceci constitue la seconde partie de cette thèse. Cette capacité, l'agilité, est fortement influencée par la manière dont le réseau logistique est conçu et dimensionné. Notre seconde problématique, traitée en troisième partie de thèse, consiste donc à assurer un niveau déterminé d'agilité aux chaînes logistiques humanitaires en les aidant à mieux positionner leurs ressources. L'objectif est de montrer que l'on peut obtenir ce niveau en maximisant l'efficience du réseau. Nous avons donc quantifié, en terme de coûts et de niveau de service, l'impact de plusieurs décisions stratégiques telles que : la proximité des fournisseurs, le degré de centralisation du réseau ou encore le niveau d'agilité visé par l'organisation. Ces deux objectifs de recherche sont illustrés par la figure 14.7.

Les organisations humanitaires doivent développer des solutions leur permettant de distribuer les secours rapidement après une crise. L'un des principaux points forts des logisticiens humanitaires est donc leur capacité à répondre rapidement et efficacement à de nombreux changements à court terme concernant la demande, l'approvisionnement ou l'environnement. C'est ce qu'on appelle l'agilité. Or, cette capacité est une propriété fondamentale que de nombreuses chaînes logistiques industrielles souhaiteraient acquérir pour réagir de façon pertinente aux évolutions constantes de leurs marchés. En effet, de nombreux secteurs industriels sont confrontés à une volatilité de plus en plus importante de la demande. Ils doivent également faire face à de nombreuses autres perturbations internes ou externes. Cette étude peut donc leur permettre de bénéficier de l'expertise de leurs homologues du secteur humanitaire et les aidera à développer des outils et méthodes leur permettant de faire face plus rapidement aux divers changements à court terme. Quant aux humanitaires, cette formalisation doit leur permettre de mieux assimiler et utiliser des connaissances d'une crise à l'autre. Elle leur servira également à mieux comprendre ce qu'il leur reste à faire pour augmenter leur niveau d'agilité.

La figure 14.8 résume notre démarche de recherche.

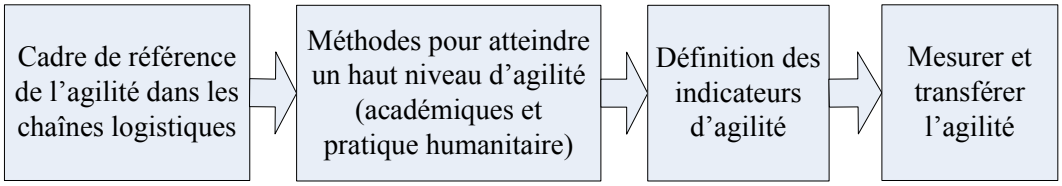


FIGURE 14.8: Partie II - résumé

Dans la seconde partie de ce manuscrit, nous explicitons les bonnes pratiques qui permettent aux humanitaires d'atteindre un haut niveau d'agilité. Dans ce but, nous avons effectué une recherche sous la forme d'une étude de cas ainsi qu'une revue de littérature. Trois dimensions de performance ont été identifiées : la flexibilité, la capacité de réponse et l'efficacité. Toutes trois sont composées de deux à quatre éléments qui, ensembles, permettent à une supply chain d'atteindre un haut niveau d'agilité (c.f. figure 14.9).

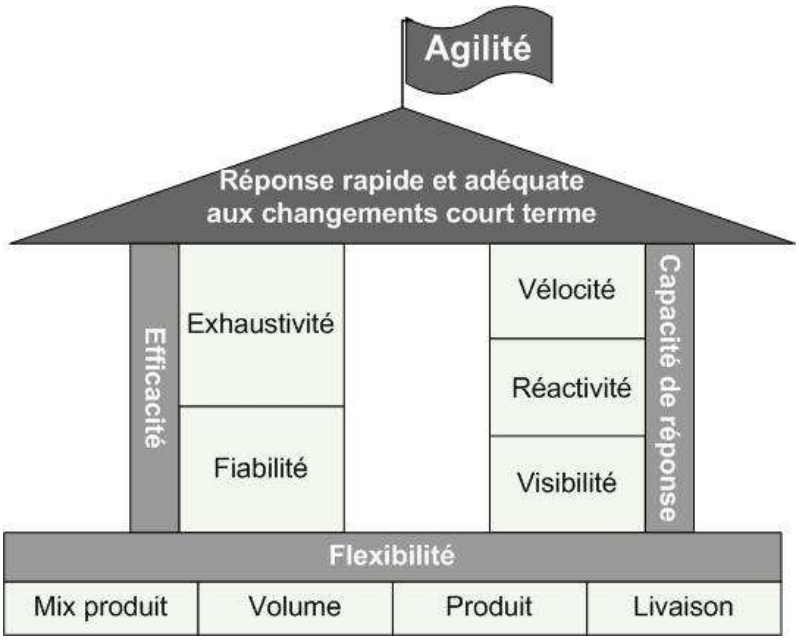


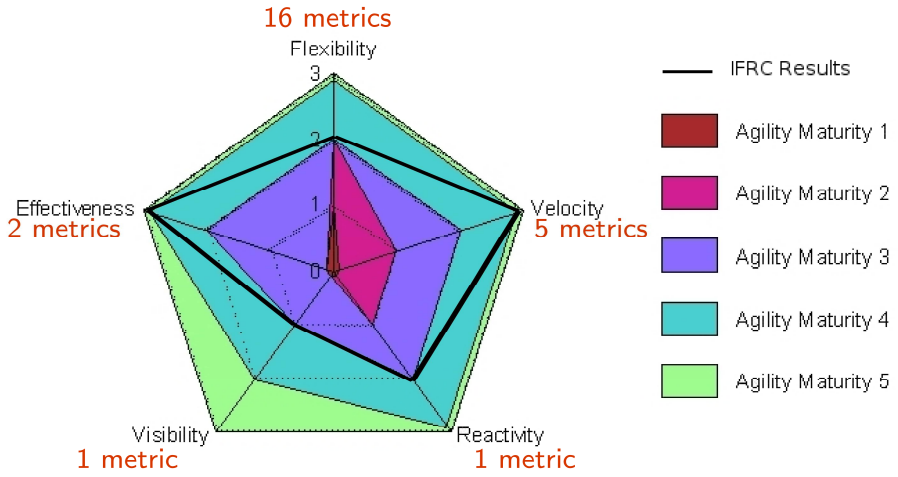
FIGURE 14.9: Maison de l'agilité des chaînes logistiques

L'objectif de cette étude est de fournir un modèle permettant de mesurer l'agilité des chaînes logistiques de façon objective, robuste et reproductible. Ces caractéristiques sont essentielles afin de pouvoir utiliser le modèle comme outil de discussion commun facilitant les benchmarks et permettant de mettre en valeur un avantage concurrentiel reconnu : l'agilité. Le modèle en lui-même est détaillé dans la partie II (voir chapitre 7) ainsi qu'en appendice. Il consiste à évaluer une chaine logistique sur chacune de des dimensions de performance de l'agilité en utilisant des grilles comme la table 14.6. Les cases grises de ce tableau correspondent à notre évaluation pour la réponse de la Fédération Internationale de la Croix Rouge et du Croissant Rouge (IFRC) à Yogyakarta[8].

[8] C'est le tremblement de terre ayant fait le plus de victimes en 2006 (cf l'étude de cas présentée dans la partie I)

TABLE 14.6: Evaluation de la vélocité des chaines logistiques

		Score = 0	Score = 1	Score = 2	Score = 3
Velocity, 5 metrics	Percentage of workforce in self directed teams	Less than 20% of workers are organized in teams	Between 20% and 60% of workers are organized in teams	Between 60% and 80% of workers are organized in teams	More than 80% of workers are organized in teams
	Number of organisational levels	More than 6 organisational levels	5 or 6 organisational levels	3 or 4 organisational levels	Less than 3 organisational levels
	Authority level at which risks can be taken and decisions are made	No authority at field level	Field workers have to wait for the person in charge of them to approve before acting	Significant changes need approval from hierarchy	Worker can act if necessity is there
	Presence/ exhaustiveness of contingency plans	No contingency plan exists	Presence of a contingency plan, but rough	Presence of a contingency plan, but not sufficiently detailed	Presence of an exhaustive contingency plan
	Number of emergency response teams	No emergency teams	Some emergency teams, but just enough to cope with less than 50% of uncertainties	Some emergency teams, but just enough to cope with 50 to 90% uncertainties	Enough emergency teams to cope with uncertainties
Assessment of Supply Chain Velocity		$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 5$	$5 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 10$	$10 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 14$	$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) \geq 14$



Improvement paths :

- Visibility : Information system to track and spread information about nature, number and status of entities transiting the supply chain (end to end)
- Reactivity : Coordinate with other organization to pool field assessments reports
- Flexibility : Improve supply chain network design

FIGURE 14.10: Conclusions de l'évaluation de la chaine logistique de l'IFRC à Yogyakarta

Ces scores sont ensuite utilisés pour estimer le niveau global d'agilité de la chaine logistique et en déduire les possibilités d'amélioration. La figure 14.10 montre un résumé de notre évaluation de la réponse de l'IFRC à Yogyakarta. Le nombre de métriques nécessaires pour décrire entièrement chaque dimension de performance varie. Deux métriques suffisent pour mesurer l'efficacité alors que 16 sont nécessaire pour la flexibilité. Cette inégalité est prise en compte dans l'élaboration de la note globale pour l'agilité. En effet, un score minimum pour chacune des dimensions de performance est nécessaire pour chaque niveau d'agilité (voir chapitre 7).

Cette deuxième partie de la thèse vise donc à clarifier les différents éléments qui permettent une réponse rapide. Près de 45% de ces éléments sont étroitement liés à la façon dont le réseau logistique des organisations est conçu et dimensionné. Cela nous a donc conduit à définir une troisième problématique afin d'aider les humanitaires à mieux appréhender les différents paramètres qui interviennent lors de la conception de leur réseau logistique. En effet, les organisations humanitaires répondent aux crises naturelles en envoyant de l'aide sur place. Pour y arriver, elles mettent en place des stocks avancés de différentes ressources. L'objet de cette étude est de configurer, puis dimensionner le réseau logistique d'une organisation humanitaire. La première étape consiste donc à déterminer l'emplacement optimal pour pré-positionner les ressources. Cette étude est exposée dans la troisième partie du manuscrit.

L'objectif n'est pas d'obtenir un très haut niveau d'agilité coûte que coûte, ce qui serait irréaliste compte tenu des ressources souvent limitées des organisations humanitaires. Il s'agit plutôt de choisir le niveau d'agilité le plus adapté, puis de concevoir la chaîne logistique qui atteint ce niveau au moindre coût. Notre étude consiste donc non seulement à assurer un niveau déterminé d'agilité des chaînes logistiques humanitaires en les aidant à mieux positionner leurs ressources, mais également à montrer que l'on peut obtenir ce niveau en maximisant leur efficience. La prise en compte de l'efficience est en effet devenue critique

dans le monde humanitaire. La nature géographiquement distribuée des interventions et le manque de coordination évident des acteurs de l'humanitaire limitent l'efficience des interventions. Or le nombre croissant de crises humanitaires et l'apparition de nouvelles organisations pour y faire face est loin d'être suivi par un accroissement des donations. Les donateurs sont de plus en plus regardants sur l'utilisation de leurs dons. Ils réclament plus de garanties et de transparence. Maximiser l'efficience des opérations humanitaires va donc dans ce sens. Notre objectif est de montrer que pour un même niveau de ressources, il est possible de secourir un plus grand nombre de victimes. Les chaînes logistiques industrielles, elles, disposent de méthodes et d'outils qui leur permettent de maîtriser cette composante de leur performance. La deuxième problématique scientifique est donc d'améliorer l'efficience des chaînes logistiques humanitaires en les aidant à mieux positionner leurs ressources.

Notre étude est divisée en trois étapes, comme illustré par la figure 14.11. Nous construisons une demande humanitaire pour une période donnée, puis nous identifions les régions les plus propices pour maintenir des stocks avancés. Ensuite, nous analysons différents critères locaux, comme l'accessibilité, la sécurité, les facilités de douane ou encore le réseau telecom.

La première étape de cette étude est de construire un état des lieux des différents réseaux existant, les localisations choisies ainsi que les différentes motivations qui poussent les humanitaires à décentraliser de plus en plus leurs réseaux. C'est l'objet des chapitres 8 et 9. Une revue des différentes possibilités que nous avons pour effectuer cette étude est ensuite fournie dans le chapitre 10.

Pour notre étude, nous avons retenu l'IFRC[9] comme sujet. En effet, l'IFRC a fait de cette problématique une priorité pour 2010. De ce fait, nous avons construit les hypothèses de notre modèle sur la base des renseignements qu'ils nous ont fourni. Nous avons toutefois fait en sorte que le modèle construit soit applicable très facilement pour n'importe quelle autre organisation.

Il nous a également fallu bien comprendre quelle était la demande humanitaire actuelle et comment elle est susceptible d'évoluer dans le future. C'est l'objet du chapitre 11. Notre analyse montre que la demande humanitaire ne sera modifiée que pour quelques cas de figure. L'augmentation du nombre et de l'impact des crises est surtout visible pour les inondations et les tempêtes dans les régions asiatiques par exemple. La figure 14.12 résume les principaux éléments de cette étude.

La rapidité de réponse est primordiale, pour les victimes surtout, mais également pour l'image médiatique de l'organisation. De ce fait, en cas de crise, si l'organisation choisit d'intervenir, il lui faut pouvoir livrer 5000 familles dans les 48h qui suivent l'évaluation de la demande. Cette évaluation est publiée généralement 3 jours après la crise. En effet, les premiers jours sont consacrés à la recherche des corps et monopolisent les moyens humains. Dans notre modèle, on a donc retenu 5000 familles dans les 5 jours qui suivent la crise, puis 15000 familles dans les 15 jours et enfin l'ensemble des besoins en 2 mois.

Les hypothèses du modèle d'optimisation régional sont les suivantes. La demande humanitaire peut être satisfaite en envoyant les produits directement depuis n'importe quel entrepôt capable de livrer dans les temps si le produit y est en stock. Les livraisons peuvent s'effectuer par avion ou par bateau, selon l'urgence de la situation. L'avion, plus rapide mais aussi plus coûteux que le bateau, sera utilisé principalement pendant les premiers jours qui suivent la crise, de manière à garantir un délai de livraison respectant les contraintes énoncées ci-dessus. Le transport par bateau prend ensuite le relais dès que les délais de livraisons le permettent.

[9] Fédération Internationale de la Croix Rouge et du Croissant Rouge

FIGURE 14.11: Overview - What are we doing exactly?

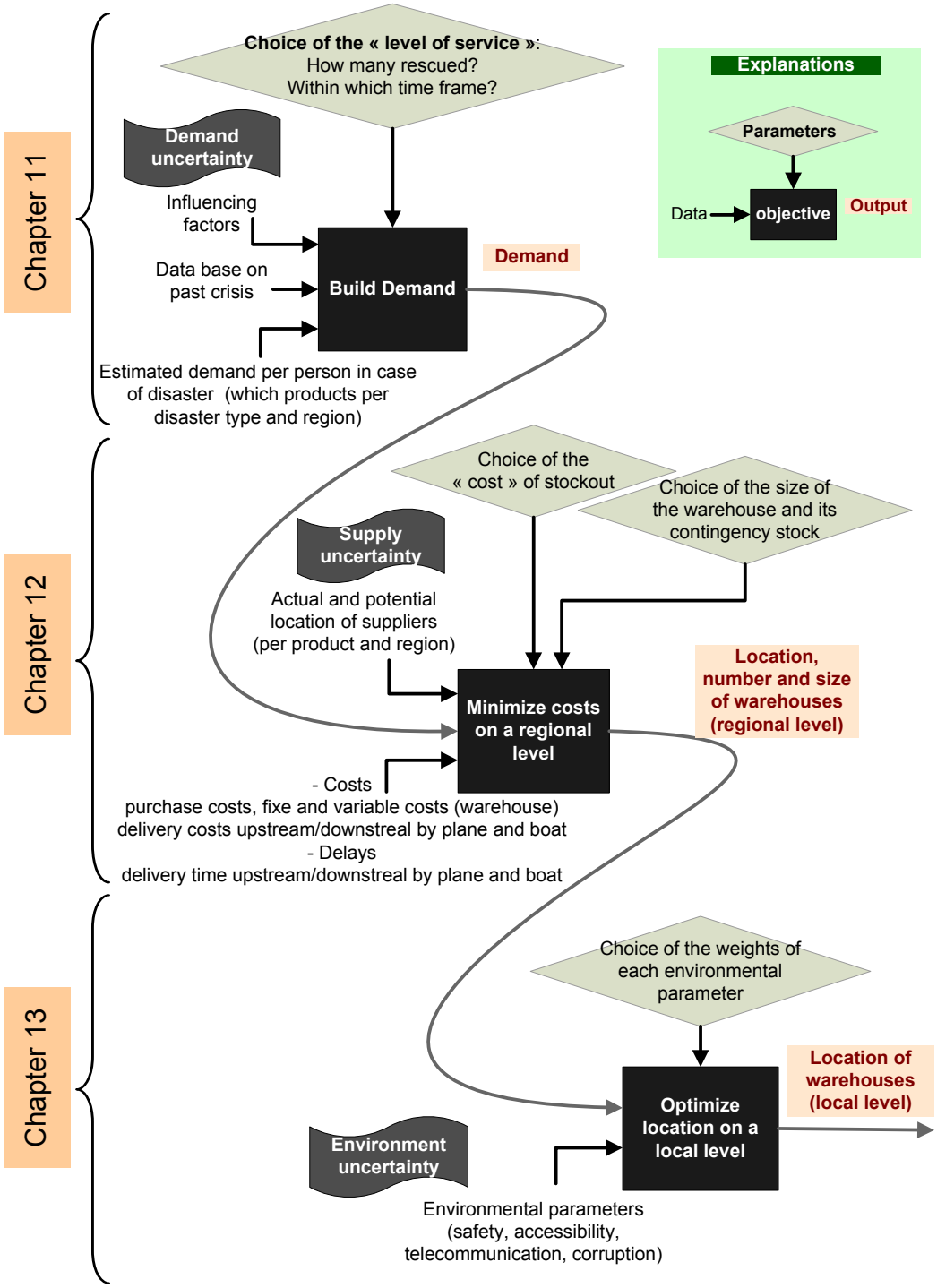
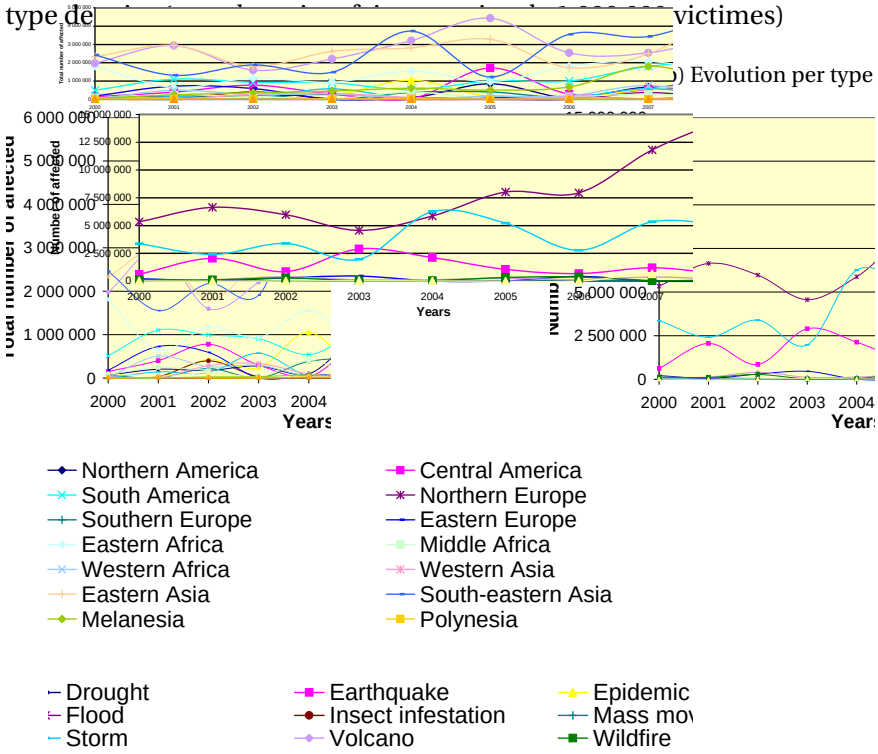


FIGURE 14.12: Evolution du nombre de victimes de crises naturelles, selon les régions et selon le type de victimes)



Il s'agit donc d'une problématique de service, où l'objectif est de satisfaire, au moindre coût, toute la demande dans les délais impartis. Les coûts à prendre en compte regroupent les coûts de transports amont et aval, à savoir du fournisseur à l'entrepôt, puis de l'entrepôt au bénéficiaire final, par bateau ou par avion. Ils prennent également en compte les coûts de fonctionnement ainsi que les coûts d'ouverture des entrepôts. Nous avons aussi tenu compte des entrepôts existants.

Si l'on connaît la ou les crises en cours, donc les demandes, le problème de localisation optimale des entrepôts peut se formuler comme un programme linéaire en variable 0, 1. Ce programme au stade actuel vise à minimiser les coûts. La satisfaction de la demande est une contrainte, avec intervention d'un "coût" de pénurie prohibitif si la contrainte ne peut être respectée. Ce programme utilise la version 110 du solveur CPLEX d'Ilog. Il a été développé avec l'interface IDE d'Ilog puis converti en java afin de faciliter la construction des scénarios de crise et le traitement des résultats. Il détermine la (les) régions qui devraient accueillir des stocks avancés.

Pour chaque scénario (un scénario étant un ensemble de crises naturelle ayant lieu dans le même laps de temps), le modèle détermine le nombre et la localisation optimale des stocks avancés. Une étude des résultats obtenus pour les 173 scénarios permet de faire ressortir les entrepôts les plus souvent choisis et les critères de sélections. Le modèle est ensuite relancé pour tous ces scénarios, mais en imposant l'ouverture d'un ou plusieurs entrepôts. Les résultats obtenus sont ensuite comparés, de manière à déterminer quelles sont les principales possibilités pour concevoir un réseau logistique optimal ou pour améliorer un réseau existant.

Une étude de sensibilité sur les critères demandés est également détaillée afin de déterminer quelles sont les décisions les plus importantes en termes de coût. Elle permet d'apporter une vision plus objective sur les questions suivantes :

1. Pourquoi choisir de décentraliser le réseau logistique humanitaire ?

2. Quels paramètres jouent un rôle important dans la décision ?

3. La décision sera-t-elle également valable d'ici 5 à 10 ans lorsque le réseau de fournisseurs locaux sera plus développé ?

Le chapitre 13 répond donc à ces différentes questions. Les réponses sont apportées en trois temps. En premier lieu, nous apportons des éléments de réponses de manière "absolue", sans tenir compte des réseaux existants. De cette analyse, il ressort qu'il est préférable de se contenter d'un seul niveau dans le réseau et que le développement du réseau de fournisseurs locaux peut permettre de gagner environ 15% en termes de coûts par exemple.

Ensuite, nous analysons un réseau existant afin de déterminer quels axes d'améliorations il est souhaitable de suivre. Ainsi, par exemple, l'IFRC gagnerait à la fois en termes de coût et en niveau de service avec un, voire deux entrepôts supplémentaires en Asie Sud-Centrale ou Sud-Est et en Afrique de l'Est. Comme précédemment, le développement du réseau local impacte le coût et les délais de réponse. Le tableau 14.7 commpare différentes options pour améliorer le réseau existant à l'IFRC.

Enfin, nous concluons notre analyse en regardant la sensibilité du modèle à quelques paramètres clés. Ainsi, si une organisation obtient une réduction de ses coûts fixes grâce à des accords avec les gouvernements (comme à Dubai) ou en se positionnant sur le même emplacement qu'une autre organisation (comme à Panama), alors ces emplacements sont privilégiés par le programme (voir figure 14.13)

FIGURE 14.13: Impact des coûts fixes sur la localisation des entrepôts
173 runs corresponding to the natural crisis of year 2008

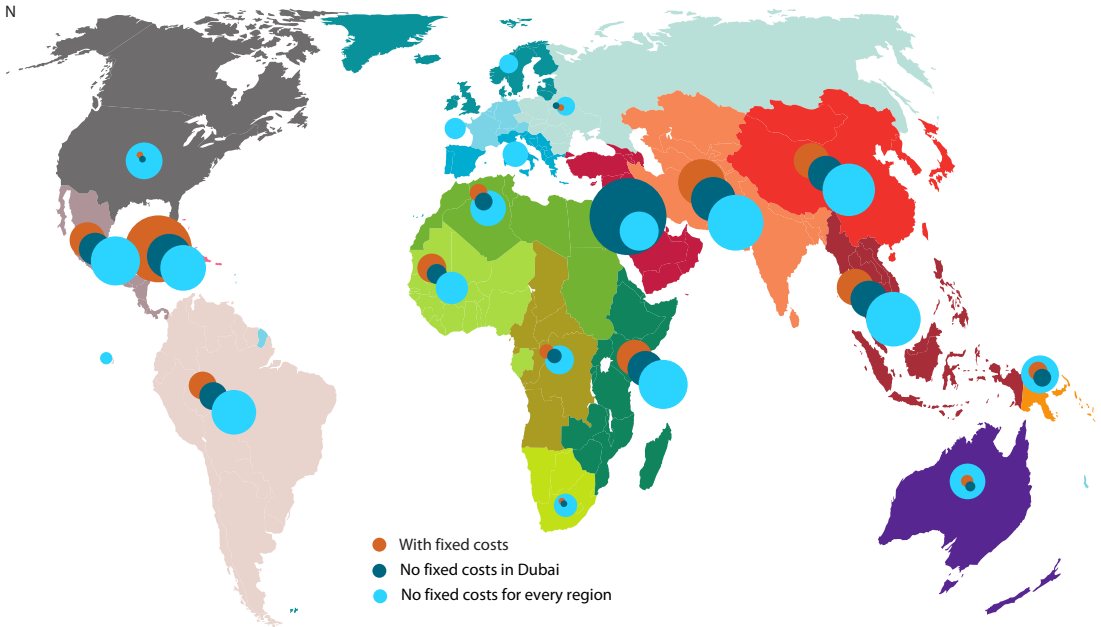


TABLE 14.7: Comparison des différentes possibilités pour améliorer le réseau de l'IFRC
"Total Costs" donne le total en coûts réels (sans compter les ruptures) pour répondre, sur une période de 1 an, à toutes les crises naturelles affectant plus de 100 personnes

	Same locations than IFRC network			Change in locations of existing warehouses					
	No change	Bigger contingency stocks	Local supply	Plus one warehouse	Minus one warehouse	Plus 2 warehouses	Plus 3 warehouses	Relocate warehouses	Relocate + local supply
Western Asia	X	X	X	X		X	X		
Central America	X	X	X	X	X	X	X		
South-Eastern Asia	X	X	X	X	X	X	X		
South Central Asia				X		X	X	X	X
Eastern Africa						X	X	X	X
Carribean							X	X	X
Number of warehouses	3	3	3	4	2	5	6	3	3
Total real costs (€)	11,3E+09€	11,2E+09€	10,2E+09€	10,7E+09€	10,9E+09€	10,6E+09€	10,6E+09€	10,32E+09€	10,1E+09€
Possible savings (real costs)	0%	0,9%	9,7%	5,3%	3,5%	6,2%	6,2%	8,7%	10,6%
Percentage of scenarios with stock-outs	3%	0,5%	0%	3%	9%	2%	1%	3%	2%
Total stock-out (nb products late x nb days waiting)	878 605	56 808	0	168 916	2 319 460	88 926	56 808	358 620	98 421
Total costs incl. fictive stockout costs	1,22E+10	1,13E+10	1,02E+10	1,09E+10	1,32E+10	1,07E+10	1,07E+10	1,07E+10	1,02E+10
Possible savings (incl. Stockout costs)	0%	7,6%	16,25%	10,75%	– 8,55%	12,2%	12,5%	12,3%	16,3%

La figure 14.14 fournit les principales réponses apportées dans le chapitre 13. Les cercle de diamètre plus élevés correspondent aux entrepôts ayant un taux d'utilisation plus élevé.

La dernière étape de notre travail d'optimisation consiste à inclure des considérations supplémentaires, cette fois à un niveau local, afin de sélectionner le(s) "meilleur(s)" pays pour établir un entrepôt. C'est l'objet du chapitre 14.

Dans ce chapitre, nous utilisons plusieurs analyses en composante principale afin de sélectionner différents sous-critères et de les agréger pour obtenir une note de référence pour chaque pays. Quatre critères sont évalués : accessibilité, sécurité, corruption et télécommunications.

De cette étude, on peut conclure qu'un entrepôt en Inde ou à Singapour serait pertinent.

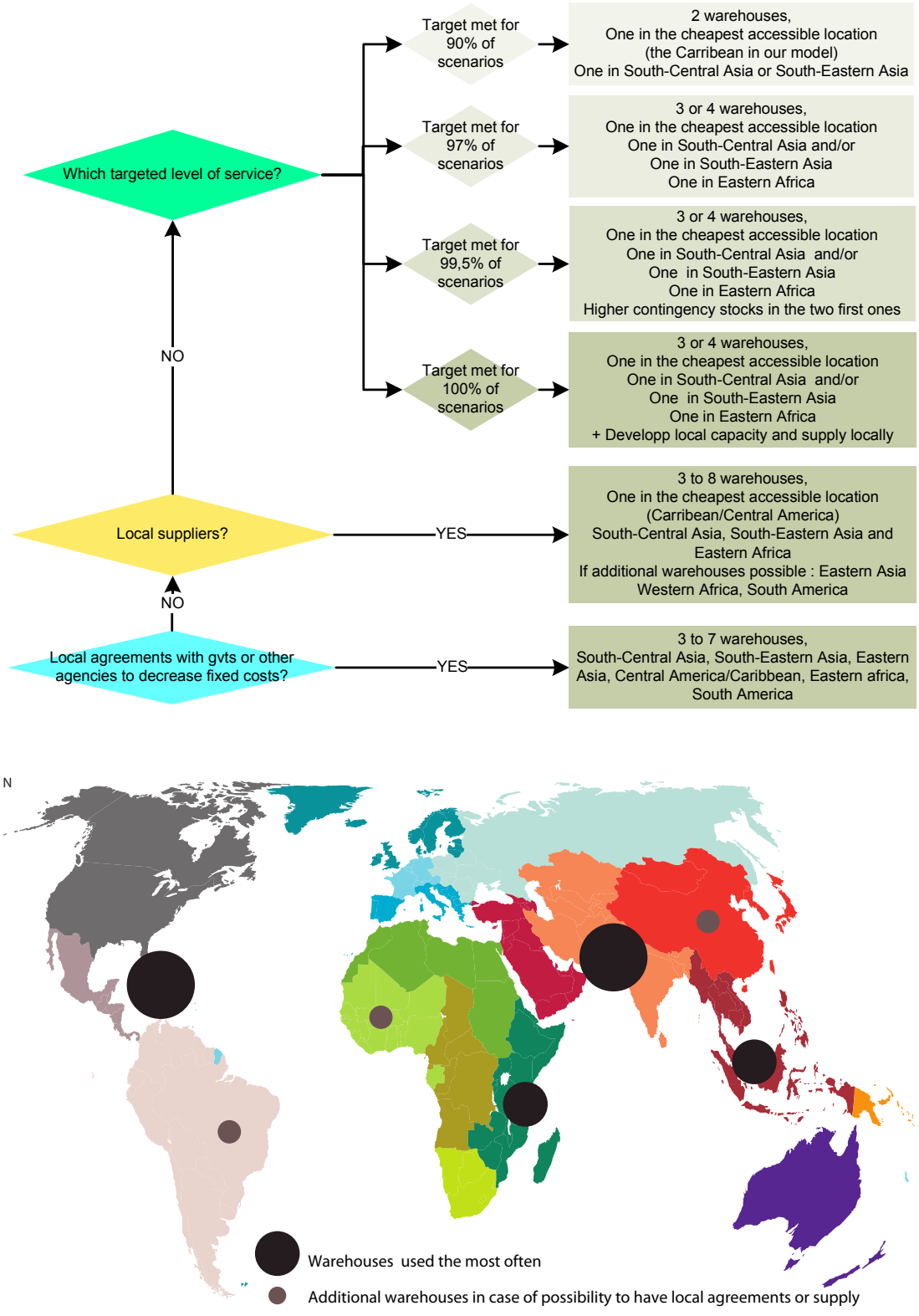
Ce travail d'optimisation correspond à un besoin réel de plusieurs associations humanitaires. Nous avons ainsi fourni des réponses objectives à quelques questions vitales pour les organisations humanitaires :

- "Comment peut-on assurer une réponse rapide et adéquate aux crises humanitaires ?"
- "Où doit-on positionner nos stocks avancés, en quelle quantité, et pour quelles raisons ?"
- "Quels sont les paramètres qui impactent les processus de décision ?"

Ce travail d'analyse a été mené en prenant soin de bien expliciter et consolider les savoir-faire des humanitaires. Les modèles proposés, bien que appliqués à une organisation pour nos travaux, ont été conçu pour être facilement adaptable à d'autres organisations. En effet, nous avons axé notre étude sur la fédération internationale de la croix rouge et du croissant rouge. Cependant, d'autres associations, comme la croix rouge Française, ont témoigné leur vif intérêt pour cette question.

Plusieurs perspectives de recherche découlent de ces travaux. Quelques suites à donner directes sont à travailler, comme les discussions avec d'autres praticiens pour valider les résultats, l'application à d'autres organisations (humanitaires ou industrielles), l'intégration d'autres ressources comme les moyens humains et matériels dans l'étude de configuration de la chaine logistique, ou encore la comparaison avec d'autres possibilités de prendre en compte les incertitudes. Plusieurs questions, plus éloignées, méritent également une étude plus approfondie. Ainsi, comme on a pu le voir, les réseaux collaboratifs impliquant les humanitaires impactent énormément le choix de la configuration du réseau, le coût et le niveau de service de la réponse. Il est donc primordial de faciliter la mise en place de ces réseaux en développant par exemple des outils facilitant le traçage et le partage des informations.

FIGURE 14.14: Résumé des principaux éléments de réponse (chapitre 13)



Appendices

A

Supply chain agility - Assessment model

The tables to assess supply chain responsiveness is provided in chapter 7 on page 67 (see tables 7.2 on page 70 and 7.3 on page 71). This appendix complement the assessment model. It provides the grids to assess the flexibility and effectiveness of supply chains.

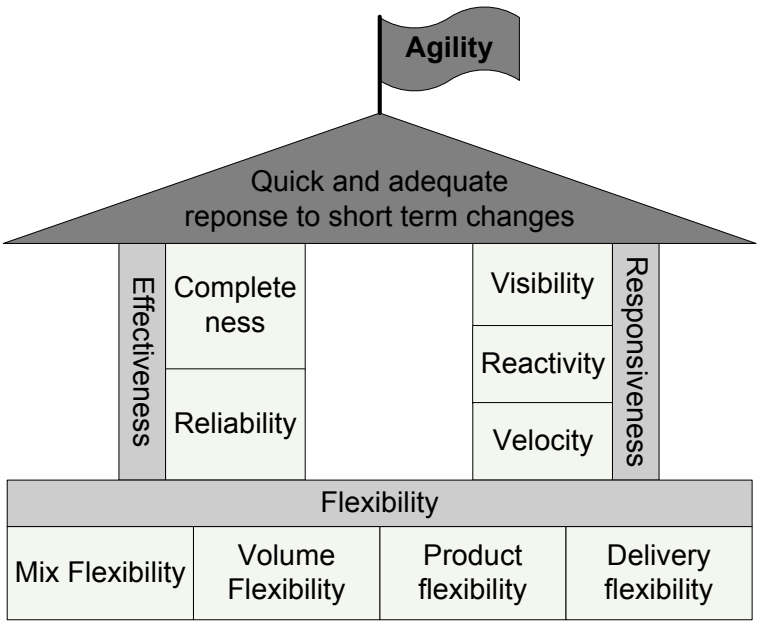


Figure A.1: House of Supply Chain Agility

Table A.1: Assessment of Supply Chain Effectiveness

		Score = 0	Score = 1	Score = 2	Score = 3
Reliability	Intermediate and end users involvement in writing products specifications	Neither intermediate nor end users are involved	Intermediate users are involved on a yearly basis. No involvement of end user	Intermediate and end users are involved on a yearly basis	Intermediate users are involved on a monthly basis and end users at least once a year
Completeness	Percentage of the demand fulfilled within acceptable time frame	Less than 50%	Between 50 and 90%	Between 90 and 97%	More than 97%
Effectiveness	Overall assessment of Supply Chain Effectiveness	$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 2$	$2 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 4$	$4 \leq \left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) < 5$	$\left(\sum \begin{matrix} Scores \\ of\ above \\ metrics \end{matrix}\right) \geq 5$

Table A.2: Assessment of Supply Chain Volume Flexibility

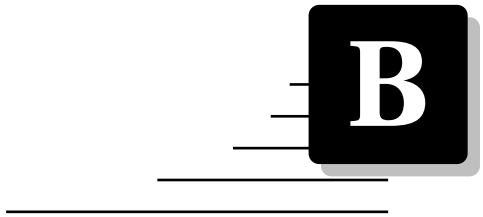
		Score = 0	Score = 1	Score = 2	Score = 3
Volume Flexibility, 8 metrics	Extent to which supplier lead time can be expedited/changed	Change is never accepted	Minor change (in days) accepted. Change has to be made more than 1week prior planned delivery	Major change (in weeks) accepted. Change has to be made more than 2days prior planned delivery	Any realistic change is accepted
	Extent of flexibility (options) within supplier contracts	No option in contracts, no pre-disaster contract	Supplier contracts have a limited number of options	Every supplier contract has options, but their range are limited	Every Contract stipulate explicitly that any realistic change is accepted
	Number of suppliers selected per component on a global basis	No clear list of suppliers	1 supplier selected per component	1, sometimes 2 suppliers selected per component	At least 2 suppliers selected per components
	Number of components purchased per supplier	No idea	2 or 3 ; Not enough to be considered as a regular customer for the supplier	4 or 5 ; Enough to be a regular customer for the supplier	> 5 ; Enough to be an important regular customer for the supplier
	Range of possible order sizes from suppliers	Always the same order size	Order size can vary, but there is a min and max order size	Order size can vary, but small or big orders require specific conditions	Any size accepted
	Number of end users supported by each distribution facility	One customer assigned per facility	Each customer can be supported by at least two facilities	Each facility is able to support more than half the customers	Any facility is able to send to any customer
	Adequacy between worldwide storage capacity and needs	No idea	Stock-out appear more than 3 times a year stock-out	Stock-out appear less than 3 times a year stock-out	Available stocks are sufficient to prevent any stock-out
	Adequacy between global delivery capacity and needs	No idea	Delivery capacity is dimensioned on standard customer orders only	High volumes can be delivered, but not always within acceptable timeframe	Any customer order can be delivered within acceptable timeframe

Table A.3: Assessment of Supply Chain Delivery, Mix and Product Flexibility

		Score = 0	Score = 1	Score = 2	Score = 3
Delivery Flexibility	Number of worldwide storage/distribution facilities	None	1	2	3 or more
	Percentage of user orders filled from alternate global facilities	None	Less than 30%	Between 30 and 60%	More than 60%
	Number of adequate available delivery modes	No idea	Usually 1 or 2, but not always for extreme situations	At least 2 for standard orders, 1 for most extreme situations	At least 2, even for extreme situations
	Number of carriers used for each type of delivery mode, on average	No idea	1 or 2	2 or 3	At least 3
	Delivery lead times	No idea	Delivery may take more than a week	Delivery is possible within 5days	Delivery is possible within 24h
Mix Flexibility	Number of items handled by each distribution facility, on average	No idea	Less than 10% of product mix	Between 10 and 50% of product mix	More than 50% of product mix
	Average number of items per order handled by each distribution facility	No idea	Less than 50% of items per order	Between 50 and 95% of items per order	Usually every items per order
Product Flexibility	Level of customization	Less than 20% of products can be modified if needed	Between 20% and 60% of products can be modified if needed	Between 60% and 90% of products can be modified if needed	More than 90% of products can be modified if needed

Table A.4: Assessment of Supply Chain Flexibility

		Score = 0	Score = 1	Score = 2	Score = 3
Flexibility	Assessment of Volume Flexibility	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 8$	$8 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 16$	$16 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 22$	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) \geq 22$
	Assessment of Delivery Flexibility	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 5$	$5 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 10$	$10 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 14$	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) \geq 14$
	Assessment of Mix Flexibility	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 2$	$2 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 4$	$4 \leq \left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) < 5$	$\left(\sum \begin{matrix} Scores \\ of \\ metrics \end{matrix}\right) \geq 5$
	Assessment of Product Flexibility	Score = 0	Score = 1	Score = 2	Score = 3
	Overall assessment of Supply Chain Flexibility	$\sum \begin{pmatrix} Scores\ of \\ Volume, \\ Delivery, \\ Mix\ and \\ Product \\ flexibility \end{pmatrix} < 4$	$\sum \begin{pmatrix} Scores\ of \\ Volume, \\ Delivery, \\ Mix\ and \\ Product \\ flexibility \end{pmatrix} \geq 4$	$\begin{cases} Volume\ Flexibility \geq 2 \\ Delivery\ Flexibility \geq 2 \\ Mix\ Flexibility = 3 \\ Product\ Flexibility \geq 1 \end{cases}$	$\begin{cases} Volume\ Flexibility = 3 \\ Delivery\ Flexibility = 3 \\ Mix\ Flexibility = 3 \\ Product\ Flexibility \geq 2 \end{cases}$



Warehouse location on a regional level - Data set

In this appendix, data for the optimization model are provided.

- DTPD - Delivery times by plane, from warehouses to affected regions
- DTBD - Delivery times by boat, from warehouses to affected regions
- DCPD - Delivery costs by plane, from warehouses to affected regions
- DCBD - Delivery costs by boat, from warehouses to affected regions
- DCPU - Delivery times by plane, from suppliers to warehouses

  (similar to DCPD, but with "99999" when there is no suppliers in a region, or when a supplier supplies only specific areas)
- DCBU - Delivery times by boat, from suppliers to warehouses

  (similar to DCPD, but with "99999" when there is no suppliers in a region, or when a supplier supplies only specific areas)
- DTPU - Delivery costs by plane, from suppliers to warehouses (similar to DTPD)
- DTBU - Delivery times by boat, from suppliers to warehouses (similar to DTBD)
- CostA - Purchase costs
- CostV - Variable costs
- CostF - Fixed costs

DTPD
(days)
Values = 2days (order treatment + loading + unloading) + average sped of cargo plane x distance

		R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	2	3,6	3,3	3,2	2,9	3,6	2,3	2,5	3,5	3,7	3,7	3,5	2,5	3,4	3,1	2,7	3,2	3,7	3,7	3,5	3,8
R1	Caribbean	3,6	2	2,3	3,3	3,5	2,9	3,6	3,5	3	2,8	2,9	2,3	3,1	2,4	3,5	3,8	3,2	2,8	2,7	3,1	2,8
R2	Central America	3,3	2,3	2	3,6	3,4	3,1	3,3	3,3	3,3	3	3,1	2,2	2,8	2,6	3,6	3,7	3,5	3	3	3,3	3
R3	Eastern Africa	3,2	3,3	3,6	2	3	2,6	3,4	3,3	2,3	2,8	2,5	3,4	3,7	3,1	2,5	2,8	2,3	2,6	2,5	2,5	2,7
R4	Eastern Asia	2,9	3,5	3,4	3	2	2,8	2,7	2,4	3,1	2,8	3	3,2	3	3,9	2,4	2,4	3,2	2,9	3,3	2,8	2,9
R5	Eastern Europe	3,6	2,9	3,1	2,6	2,8	2	3,4	3,2	2,6	2,2	2,2	2,9	3,7	3,1	2,5	2,9	2,9	2,2	2,5	2,2	2,2
R6	Melanesia	2,3	3,6	3,3	3,4	2,7	3,4	2	2,3	3,6	3,5	3,6	3,3	2,4	3,6	3	2,6	3,4	3,6	3,9	3,4	3,6
R7	Micronesia	2,5	3,5	3,3	3,3	2,4	3,2	2,3	2	3,5	3,2	3,4	3,2	2,6	3,8	2,8	2,5	3,4	3,4	3,7	3,2	3,3
R8	Middle Africa	3,5	3	3,3	2,3	3,1	2,6	3,6	3,5	2	2,6	2,3	3,2	3,9	2,9	2,7	3,1	2,4	2,5	2,3	2,4	2,6
R9	North Europe	3,7	2,8	3	2,8	2,8	2,2	3,5	3,2	2,6	2	2,3	2,7	3,6	3	2,7	3,1	3	2,2	2,6	2,3	2,1
R10	Northern Africa	3,7	2,9	3,1	2,5	3	2,2	3,6	3,4	2,3	2,3	2	2,9	3,9	2,9	2,6	3,1	2,7	2,1	2,3	2,2	2,2
R11	Northern America	3,5	2,3	2,2	3,4	3,2	2,9	3,3	3,2	3,2	2,7	2,9	2	3	2,7	3,4	3,5	3,5	2,8	2,9	3,1	2,8
R12	Polynesia	2,5	3,1	2,8	3,7	3	3,7	2,4	2,6	3,9	3,6	3,9	3	2	3,2	3,4	3,1	3,6	3,8	3,8	3,8	3,7
R13	South America	3,4	2,4	2,6	3,1	3,9	3,1	3,6	3,8	2,9	3	2,9	2,7	3,2	2	3,6	3,9	2,9	3	2,7	3,2	3
R14	South-central Asia	3,1	3,5	3,6	2,5	2,4	2,5	3	2,8	2,7	2,7	2,6	3,4	3,4	3,6	2	2,4	2,8	2,7	2,9	2,4	2,7
R15	South-eastern Asia	2,7	3,8	3,7	2,8	2,4	2,9	2,6	2,5	3,1	3,1	3,1	3,5	3,1	3,9	2,4	2	3	3,1	3,3	2,8	3,1
R16	Southern Africa	3,2	3,2	3,5	2,3	3,2	2,9	3,4	3,4	2,4	3	2,7	3,5	3,6	2,9	2,8	3	2	2,8	2,6	2,7	2,9
R17	Southern Europe	3,7	2,8	3	2,6	2,9	2,2	3,6	3,4	2,5	2,2	2,1	2,8	3,8	3	2,7	3,1	2,8	2	2,4	2,3	2,1
R18	Western Africa	3,7	2,7	3	2,5	3,3	2,5	3,9	3,7	2,3	2,6	2,3	2,9	3,8	2,7	2,9	3,3	2,6	2,4	2	2,5	2,5
R19	Western Asia	3,5	3,1	3,3	2,5	2,8	2,2	3,4	3,2	2,4	2,3	2,2	3,1	3,8	3,2	2,4	2,8	2,7	2,3	2,5	2	2,3
R20	Western Europe	3,8	2,8	3	2,7	2,9	2,2	3,6	3,3	2,6	2,1	2,2	2,8	3,7	3	2,7	3,1	2,9	2,1	2,5	2,3	2

DTBD
(days)
Values = 2days (order treatment + loading + unloading) + average sped of cargo boat x distance

		R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	2	18	15,4	14,4	10,7	18	4,6	7	17	19,1	18,9	16,9	7	16,4	12,8	8,7	13,8	19,5	19,4	16,9	19,5
R1	Caribbean	18	2	5	14,7	16,8	11,4	17,5	17,4	11,9	9,9	10,8	5,2	13,3	6,1	16,7	20,2	13,9	10,2	9,3	12,7	9,8
R2	Central America	15,4	5	2	17,7	15,7	13,2	14,5	14,6	14,9	11,6	13,3	4,4	10,5	8	17,9	18,9	16,7	12,4	12,3	14,9	11,8
R3	Eastern Africa	14,4	14,7	17,7	2	11,6	8,2	15,5	14,8	4,8	9,7	6,9	16,3	19,4	13	7,3	10	5,1	8,1	7,5	6,5	9
R4	Eastern Asia	10,7	16,8	15,7	11,6	2	9,6	8,8	6,4	13,4	10,3	11,7	13,9	12,5	20,6	6,3	5,5	14,4	11,3	14,8	9,5	10,9
R5	Eastern Europe	18	11,4	13,2	8,2	9,6	2	16,4	13,9	7,5	3,7	4,4	11	18,9	13,2	7,3	11,3	10,8	3,7	7,4	3,8	3,6
R6	Melanesia	4,6	17,5	14,5	15,5	8,8	16,4	2	4,6	18,3	16,9	18,4	15,2	6,5	17,9	12	8	15,9	18,1	20,9	16,1	17,6
R7	Micronesia	7	17,4	14,6	14,8	6,4	13,9	4,6	2	17,3	14,3	16,1	14,3	8,2	19,9	10,2	6,8	16,4	15,6	19,2	13,9	15,1
R8	Middle Africa	17	11,9	14,9	4,8	13,4	7,5	18,3	17,3	2	8,4	5,3	13,9	21,3	10,6	9,2	12,6	5,5	6,6	4,7	6,4	7,6
R9	North Europe	19,1	9,9	11,6	9,7	10,3	3,7	16,9	14,3	8,4	2	5,1	9,3	18	12,3	8,8	12,6	11,9	3,9	7,5	5,4	2,9
R10	Northern Africa	18,9	10,8	13,3	6,9	11,7	4,4	18,4	16,1	5,3	5,1	2	11,5	21,2	11,4	8,5	12,6	8,8	3,3	5,1	4,3	4,3
R11	Northern America	16,9	5,2	4,4	16,3	13,9	11	15,2	14,3	13,9	9,3	11,5	2	12	9,2	15,5	17,4	16,7	10,4	11,3	12,7	9,7
R12	Polynesia	7	13,3	10,5	19,4	12,5	18,9	6,5	8,2	21,3	18	21,2	12	2	13,7	16,4	12,5	17,8	19,9	20,3	19,9	18,8
R13	South America	16,4	6,1	8	13	20,6	13,2	17,9	19,9	10,6	12,3	11,4	9,2	13,7	2	17,7	20,8	10,9	11,6	8,6	13,7	11,8
R14	South-central Asia	12,8	16,7	17,9	7,3	6,3	7,3	12	10,2	9,2	8,8	8,5	15,5	16,4	17,7	2	6,1	10,3	8,7	11,1	6,2	8,9
R15	South-eastern Asia	8,7	20,2	18,9	10	5,5	11,3	8	6,8	12,6	12,6	12,6	17,4	12,5	20,8	6,1	2	11,9	12,8	15	10,3	12,8
R16	Southern Africa	13,8	13,9	16,7	5,1	14,4	10,8	15,9	16,4	5,5	11,9	8,8	16,7	17,8	10,9	10,3	11,9	2	10,1	7,6	9,3	11,1
R17	Southern Europe	19,5	10,2	12,4	8,1	11,3	3,7	18,1	15,6	6,6	3,9	3,3	10,4	19,9	11,6	8,7	12,8	10,1	2	5,8	4,6	3
R18	Western Africa	19,4	9,3	12,3	7,5	14,8	7,4	20,9	19,2	4,7	7,5	5,1	11,3	20,3	8,6	11,1	15	7,6	5,8	2	7,3	6,7
R19	Western Asia	16,9	12,7	14,9	6,5	9,5	3,8	16,1	13,9	6,4	5,4	4,3	12,7	19,9	13,7	6,2	10,3	9,3	4,6	7,3	2	5,1
R20	Western Europe	19,5	9,8	11,8	9	10,9	3,6	17,6	15,1	7,6	2,9	4,3	9,7	18,8	11,8	8,9	12,8	11,1	3	6,7	5,1	2

COLUMN1 = region (warehouse) ROW1=region (affected) ; DECALAGE =products
High value => no transportation done by the company

DCPD (euros) - Values are for a box of 20 products, here woollen blankets (2kg, 0,08m³)

	P1	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	41	120	94	120	104	120	91	91	120	104	120	107	92	104	114	104	120	92	120	120	92
R1	Caribbean	68	41	53	68	82	68	68	68	68	68	68	55	68	53	104	66	68	68	68	68	53
R2	Central America	52	46	41	80	65	80	80	80	80	46	80	48	80	46	113	65	80	46	80	80	46
R3	Eastern Africa	151	151	127	41	168	194	194	194	194	151	194	144	194	151	228	168	194	127	194	151	127
R4	Eastern Asia	48	62	44	68	41	68	48	48	68	58	68	56	48	62	78	50	68	58	68	68	58
R5	Eastern Europe	191	167	167	191	184	41	191	191	191	168	99999	184	191	191	210	184	191	139	191	174	139
R6	Melanesia	41	83	50	83	50	83	41	49	83	73	83	50	65	73	72	49	83	65	83	83	65
R7	Micronesia	41	83	50	83	64	83	49	41	83	79	83	62	99999	73	99999	61	83	67	83	99999	65
R8	Middle Africa	162	156	99999	209	161	205	209	209	41	161	99999	136	209	156	226	161	209	136	209	161	136
R9	North Europe	184	209	184	232	204	198	232	232	246	41	187	202	232	209	234	208	232	150	232	187	187
R10	Northern Africa	82	84	84	108	83	66	84	84	108	53	41	67	84	84	118	74	108	50	108	82	50
R11	Northern America	88	79	65	157	100	157	118	118	157	96	157	41	118	119	125	92	157	82	157	99999	82
R12	Polynesia	143	227	226	99999	99999	99999	99999	99999	99999	99999	226	181	41	226	99999	99999	99999	99999	99999	226	99999
R13	South America	78	70	70	131	90	131	78	78	131	74	114	109	78	41	145	90	131	74	131	114	74
R14	South-central Asia	61	76	54	76	71	61	76	76	76	61	76	66	76	76	41	54	76	53	76	52	53
R15	South-eastern Asia	44	70	58	108	58	108	59	59	108	59	108	71	59	86	79	41	108	59	108	86	59
R16	Southern Africa	96	97	103	99999	99999	99999	99999	157	99999	121	99999	120	99999	121	99999	138	41	99999	99999	99999	103
R17	Southern Europe	144	152	144	182	158	95	182	182	182	76	149	137	182	151	188	162	182	41	182	149	106
R18	Western Africa	158	160	133	204	158	204	204	204	204	158	99999	133	204	158	221	158	204	133	41	158	133
R19	Western Asia	96	96	92	96	102	96	96	99999	96	85	96	101	99999	96	95	102	96	79	96	41	79
R20	Western Europe	172	185	172	192	169	167	114	192	192	142	181	156	192	185	203	172	192	70	192	181	41

DCPD (euros) - Values are for a box of 40 products, here plastic sheeting (40 products, 55kg, 0,13m³)

	P2	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	187	550	429	550	479	550	418	418	550	479	550	490	424	479	523	479	550	424	550	550	424
R1	Caribbean	314	187	242	314	374	314	314	314	314	314	314	253	314	242	479	303	314	314	314	314	242
R2	Central America	237	209	187	369	297	369	369	369	369	209	369	220	369	209	517	297	369	209	369	369	209
R3	Eastern Africa	693	693	583	187	770	891	891	891	891	693	891	660	891	693	1045	770	891	583	891	693	583
R4	Eastern Asia	220	286	204	314	187	314	220	220	314	264	314	259	220	286	358	231	314	264	314	314	264
R5	Eastern Europe	875	765	765	875	842	187	875	875	875	770	99999	842	875	875	963	842	875	638	875	798	638
R6	Melanesia	187	380	231	380	231	380	187	226	380	336	380	231	297	336	330	226	380	297	380	380	297
R7	Micronesia	187	380	231	380	292	380	226	187	380	363	380	286	99999	336	99999	281	380	308	380	99999	297
R8	Middle Africa	743	715	99999	957	737	941	957	957	187	737	99999	622	957	715	1034	737	957	622	957	737	622
R9	North Europe	842	957	842	1062	935	908	1062	1062	1128	187	858	924	1062	957	1073	952	1062	688	1062	858	858
R10	Northern Africa	374	385	385	495	380	303	385	385	495	242	187	308	385	385	539	341	495	231	495	374	231
R11	Northern America	402	363	297	721	457	721	539	539	721	440	721	187	539	545	572	424	721	374	721	99999	374
R12	Polynesia	655	1040	1034	99999	99999	99999	99999	99999	99999	99999	1034	831	187	1034	99999	99999	99999	99999	99999	1034	99999
R13	South America	358	319	319	600	413	600	358	358	600	341	523	501	358	187	666	413	600	341	600	523	341
R14	South-central Asia	281	347	248	347	325	281	347	347	347	281	347	303	347	347	187	248	347	242	347	237	242
R15	South-eastern Asia	204	319	264	495	264	495	270	270	495	270	495	325	270	396	363	187	495	270	495	396	270
R16	Southern Africa	440	446	473	99999	99999	99999	99999	721	99999	556	99999	550	99999	556	99999	633	187	99999	99999	99999	473
R17	Southern Europe	660	699	660	836	726	435	836	836	836	347	682	627	836	693	864	743	836	187	836	682	484
R18	Western Africa	726	732	611	935	726	935	935	935	935	726	99999	611	935	726	1012	726	935	611	187	726	611
R19	Western Asia	440	440	424	440	468	440	440	99999	440	391	440	462	99999	440	435	468	440	363	440	187	363
R20	Western Europe	787	847	787	880	776	765	523	880	880	649	831	715	880	847	930	787	880	319	880	831	187

COLUMN1 = region (warehouse) ROW1=region (affected) ; DECALAGE =products
High value => no transportation done by the company

DCPD (euros) - Values are for one Inter Agency Emmergency Health kit (1133kg, 5,85m^3)

	P3	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	3512	10330	8057	10330	8987	10330	7851	7851	10330	8987	10330	9194	7954	8987	9814	8987	10330	7954	10330	10330	7954
R1	Caribbean	5888	3512	4545	5888	7024	5888	5888	5888	5888	5888	5888	4752	5888	4545	8987	5682	5888	5888	5888	5888	4545
R2	Central America	4442	3925	3512	6921	5578	6921	6921	6921	6921	3925	6921	4132	6921	3925	9710	5578	6921	3925	6921	6921	3925
R3	Eastern Africa	13016	13016	10950	3512	14462	16735	16735	16735	16735	13016	16735	12396	16735	13016	19627	14462	16735	10950	16735	13016	10950
R4	Eastern Asia	4132	5372	3822	5888	3512	5888	4132	4132	5888	4958	5888	4855	4132	5372	6715	4339	5888	4958	5888	5888	4958
R5	Eastern Europe	16425	14359	14359	16425	15805	3512	16425	16425	16425	14462	99999	15805	16425	16425	18078	15805	16425	11983	16425	14979	11983
R6	Melanesia	3512	7128	4339	7128	4339	7128	3512	4235	7128	6301	7128	4339	5578	6301	6198	4235	7128	5578	7128	7128	5578
R7	Micronesia	3512	7128	4339	7128	5475	7128	4235	3512	7128	6818	7128	5372	99999	6301	99999	5268	7128	5785	7128	99999	5578
R8	Middle Africa	13946	13429	99999	17974	13842	17664	17974	17974	3512	13842	99999	11673	17974	13429	19420	13842	17974	11673	17974	13842	11673
R9	North Europe	15805	17974	15805	19937	17561	17045	19937	19937	21177	3512	16115	17354	19937	17974	20144	17871	19937	12913	19937	16115	16115
R10	Northern Africa	7024	7231	7231	9297	7128	5682	7231	7231	9297	4545	3512	5785	7231	7231	10123	6405	9297	4339	9297	7024	4339
R11	Northern America	7541	6818	5578	13532	8574	13532	10123	10123	13532	8264	13532	3512	10123	10227	10743	7954	13532	7024	13532	99999	7024
R12	Polynesia	12293	19524	19420	99999	99999	99999	99999	99999	99999	99999	19420	15598	3512	19420	99999	99999	99999	99999	99999	19420	99999
R13	South America	6715	5991	5991	11260	7748	11260	6715	6715	11260	6405	9814	9400	6715	3512	12499	7748	11260	6405	11260	9814	6405
R14	South-central Asia	5268	6508	4649	6508	6095	5268	6508	6508	6508	5268	6508	5682	6508	6508	3512	4649	6508	4545	6508	4442	4545
R15	South-eastern Asia	3822	5991	4958	9297	4958	9297	5062	5062	9297	5062	9297	6095	5062	7438	6818	3512	9297	5062	9297	7438	5062
R16	Southern Africa	8264	8367	8884	99999	99999	99999	99999	13532	99999	10433	99999	10330	99999	10433	99999	11880	3512	99999	99999	99999	8884
R17	Southern Europe	12396	13119	12396	15702	13636	8161	15702	15702	15702	6508	12809	11776	15702	13016	16218	13946	15702	3512	15702	12809	9090
R18	Western Africa	13636	13739	11466	17561	13636	17561	17561	17561	17561	13636	99999	11466	17561	13636	19007	13636	17561	11466	3512	13636	11466
R19	Western Asia	8264	8264	7954	8264	8781	8264	8264	99999	8264	7334	8264	8677	99999	8264	8161	8781	8264	6818	8264	3512	6818
R20	Western Europe	14772	15908	14772	16528	14565	14359	9814	16528	16528	12189	15598	13429	16528	15908	17458	14772	16528	5991	16528	15598	3512

DCPD (euros) - Values are for one cholera kit (1078kg, 4,45m^3)

	P4	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	3665	10780	8408	10780	9379	10780	8193	8193	10780	9379	10780	9594	8301	9379	10241	9379	10780	8301	10780	10780	8301
R1	Caribbean	6145	3665	4743	6145	7330	6145	6145	6145	6145	6145	6145	4959	6145	4743	9379	5929	6145	6145	6145	6145	4743
R2	Central America	4635	4096	3665	7223	5821	7223	7223	7223	7223	4096	7223	4312	7223	4096	10133	5821	7223	4096	7223	7223	4096
R3	Eastern Africa	13583	13583	11427	3665	15092	17464	17464	17464	17464	13583	17464	12936	17464	13583	20482	15092	17464	11427	17464	13583	11427
R4	Eastern Asia	4312	5606	3989	6145	3665	6145	4312	4312	6145	5174	6145	5067	4312	5606	7007	4528	6145	5174	6145	6145	5174
R5	Eastern Europe	17140	14984	14984	17140	16493	3665	17140	17140	17140	15092	99999	16493	17140	17140	18865	16493	17140	12505	17140	15631	12505
R6	Melanesia	3665	7438	4528	7438	4528	7438	3665	4420	7438	6576	7438	4528	5821	6576	6468	4420	7438	5821	7438	7438	5821
R7	Micronesia	3665	7438	4528	7438	5713	7438	4420	3665	7438	7115	7438	5606	99999	6576	99999	5498	7438	6037	7438	99999	5821
R8	Middle Africa	14553	14014	99999	18757	14445	18434	18757	18757	3665	14445	99999	12181	18757	14014	20266	14445	18757	12181	18757	14445	12181
R9	North Europe	16493	18757	16493	20805	18326	17787	20805	20805	22099	3665	16817	18110	20805	18757	21021	18649	20805	13475	20805	16817	16817
R10	Northern Africa	7330	7546	7546	9702	7438	5929	7546	7546	9702	4743	3665	6037	7546	7546	10564	6684	9702	4528	9702	7330	4528
R11	Northern America	7869	7115	5821	14122	8947	14122	10564	10564	14122	8624	14122	3665	10564	10672	11211	8301	14122	7330	14122	99999	7330
R12	Polynesia	12828	20374	20266	99999	99999	99999	99999	99999	99999	99999	20266	16278	3665	20266	99999	99999	99999	99999	99999	20266	99999
R13	South America	7007	6252	6252	11750	8085	11750	7007	7007	11750	6684	10241	9810	7007	3665	13044	8085	11750	6684	11750	10241	6684
R14	South-central Asia	5498	6791	4851	6791	6360	5498	6791	6791	6791	5498	6791	5929	6791	6791	3665	4851	6791	4743	6791	4635	4743
R15	South-eastern Asia	3989	6252	5174	9702	5174	9702	5282	5282	9702	5282	9702	6360	5282	7762	7115	3665	9702	5282	9702	7762	5282
R16	Southern Africa	8624	8732	9271	99999	99999	99999	99999	14122	99999	10888	99999	10780	99999	10888	99999	12397	3665	99999	99999	99999	9271
R17	Southern Europe	12936	13691	12936	16386	14230	8516	16386	16386	16386	6791	13367	12289	16386	13583	16925	14553	16386	3665	16386	13367	9486
R18	Western Africa	14230	14337	11966	18326	14230	18326	18326	18326	18326	14230	99999	11966	18326	14230	19835	14230	18326	11966	3665	14230	11966
R19	Western Asia	8624	8624	8301	8624	9163	8624	8624	99999	8624	7654	8624	9055	99999	8624	8516	9163	8624	7115	8624	3665	7115
R20	Western Europe	15415	16601	15415	17248	15200	14984	10241	17248	17248	12720	16278	14014	17248	16601	18218	15415	17248	6252	17248	16278	3665

COLUMN1 = region (warehouse) ROW1=region (affected) ; DECALAGE =products
High value => no transportation done by the company

DCPD (euros) - Values are for five hygienic parcels (0,44kg, 0,01m^3)

	P5	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	15	44	34	44	38	44	33	33	44	38	44	39	34	38	42	38	44	34	44	44	34
R1	Caribbean	25	15	19	25	30	25	25	25	25	25	25	20	25	19	38	24	25	25	25	25	19
R2	Central America	19	17	15	29	24	29	29	29	29	17	29	18	29	17	41	24	29	17	29	29	17
R3	Eastern Africa	55	55	47	15	62	71	71	71	71	55	71	53	71	55	84	62	71	47	71	55	47
R4	Eastern Asia	18	23	16	25	15	25	18	18	25	21	25	21	18	23	29	18	25	21	25	25	21
R5	Eastern Europe	70	61	61	70	67	15	70	70	70	62	99999	67	70	70	77	67	70	51	70	64	51
R6	Melanesia	15	30	18	30	18	30	15	18	30	27	30	18	24	27	26	18	30	24	30	30	24
R7	Micronesia	15	30	18	30	23	30	18	15	30	29	30	23	99999	27	99999	22	30	25	30	99999	24
R8	Middle Africa	59	57	99999	77	59	75	77	77	15	59	99999	50	77	57	83	59	77	50	77	59	50
R9	North Europe	67	77	67	85	75	73	85	85	90	15	69	74	85	77	86	76	85	55	85	69	69
R10	Northern Africa	30	31	31	40	30	24	31	31	40	19	15	25	31	31	43	27	40	18	40	30	18
R11	Northern America	32	29	24	58	37	58	43	43	58	35	58	15	43	44	46	34	58	30	58	99999	30
R12	Polynesia	52	83	83	99999	99999	99999	99999	99999	99999	99999	83	66	15	83	99999	99999	99999	99999	99999	83	99999
R13	South America	29	26	26	48	33	48	29	29	48	27	42	40	29	15	53	33	48	27	48	42	27
R14	South-central Asia	22	28	20	28	26	22	28	28	28	22	28	24	28	28	15	20	28	19	28	19	19
R15	South-eastern Asia	16	26	21	40	21	40	22	22	40	22	40	26	22	32	29	15	40	22	40	32	22
R16	Southern Africa	35	36	38	99999	99999	99999	99999	58	99999	44	99999	44	99999	44	99999	51	15	99999	99999	99999	38
R17	Southern Europe	53	56	53	67	58	35	67	67	67	28	55	50	67	55	69	59	67	15	67	55	39
R18	Western Africa	58	59	49	75	58	75	75	75	75	58	99999	49	75	58	81	58	75	49	15	58	49
R19	Western Asia	35	35	34	35	37	35	35	99999	35	31	35	37	99999	35	35	37	35	29	35	15	29
R20	Western Europe	63	68	63	70	62	61	42	70	70	52	66	57	70	68	74	63	70	26	70	66	15

DCPD (euros) - Values are for two mosquito nets (4kg, 0,002m^3)

	P6	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	102	300	234	300	261	300	228	228	300	261	300	267	231	261	285	261	300	231	300	300	231
R1	Caribbean	171	102	132	171	204	171	171	171	171	171	171	138	171	132	261	165	171	171	171	171	132
R2	Central America	129	114	102	201	162	201	201	201	201	114	201	120	201	114	282	162	201	114	201	201	114
R3	Eastern Africa	378	378	318	102	420	486	486	486	486	378	486	360	486	378	570	420	486	318	486	378	318
R4	Eastern Asia	120	156	111	171	102	171	120	120	171	144	171	141	120	156	195	126	171	144	171	171	144
R5	Eastern Europe	477	417	417	477	459	102	477	477	477	420	99999	459	477	477	525	459	477	348	477	435	348
R6	Melanesia	102	207	126	207	126	207	102	123	207	183	207	126	162	183	180	123	207	162	207	207	162
R7	Micronesia	102	207	126	207	159	207	123	102	207	198	207	156	99999	183	99999	153	207	168	207	99999	162
R8	Middle Africa	405	390	99999	522	402	513	522	522	102	402	99999	339	522	390	564	402	522	339	522	402	339
R9	North Europe	459	522	459	579	510	495	579	579	615	102	468	504	579	522	585	519	579	375	579	468	468
R10	Northern Africa	204	210	210	270	207	165	210	210	270	132	102	168	210	210	294	186	270	126	270	204	126
R11	Northern America	219	198	162	393	249	393	294	294	393	240	393	102	294	297	312	231	393	204	393	99999	204
R12	Polynesia	357	567	564	99999	99999	99999	99999	99999	99999	99999	564	453	102	564	99999	99999	99999	99999	99999	564	99999
R13	South America	195	174	174	327	225	327	195	195	327	186	285	273	195	102	363	225	327	186	327	285	186
R14	South-central Asia	153	189	135	189	177	153	189	189	189	153	189	165	189	189	102	135	189	132	189	129	132
R15	South-eastern Asia	111	174	144	270	144	270	147	147	270	147	270	177	147	216	198	102	270	147	270	216	147
R16	Southern Africa	240	243	258	99999	99999	99999	99999	393	99999	303	99999	300	99999	303	99999	345	102	99999	99999	99999	258
R17	Southern Europe	360	381	360	456	396	237	456	456	456	189	372	342	456	378	471	405	456	102	456	372	264
R18	Western Africa	396	399	333	510	396	510	510	510	510	396	99999	333	510	396	552	396	510	333	102	396	333
R19	Western Asia	240	240	231	240	255	240	240	99999	240	213	240	252	99999	240	237	255	240	198	240	102	198
R20	Western Europe	429	462	429	480	423	417	285	480	480	354	453	390	480	462	507	429	480	174	480	453	102

COLUMN1 = region (warehouse) ROW1=region (affected) ; DECALAGE =products
High value => no transportation done by the company

DCPD (euros) - Values are for five kitchen kits (4,7kg, 0,022m^3)

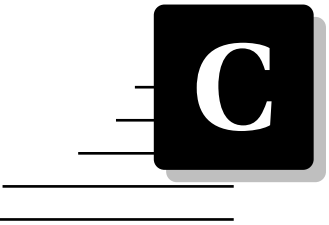
	P7	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	119	350	273	350	305	350	266	266	350	305	350	312	270	305	333	305	350	270	350	350	270
R1	Caribbean	200	119	154	200	238	200	200	200	200	200	200	161	200	154	305	193	200	200	200	200	154
R2	Central America	151	133	119	235	189	235	235	235	235	133	235	140	235	133	329	189	235	133	235	235	133
R3	Eastern Africa	441	441	371	119	490	567	567	567	567	441	567	420	567	441	665	490	567	371	567	441	371
R4	Eastern Asia	140	182	130	200	119	200	140	140	200	168	200	165	140	182	228	147	200	168	200	200	168
R5	Eastern Europe	557	487	487	557	536	119	557	557	557	490	99999	536	557	557	613	536	557	406	557	508	406
R6	Melanesia	119	242	147	242	147	242	119	144	242	214	242	147	189	214	210	144	242	189	242	242	189
R7	Micronesia	119	242	147	242	186	242	144	119	242	231	242	182	99999	214	99999	179	242	196	242	99999	189
R8	Middle Africa	473	455	99999	609	469	599	609	609	119	469	99999	396	609	455	658	469	609	396	609	469	396
R9	North Europe	536	609	536	676	595	578	676	676	718	119	546	588	676	609	683	606	676	438	676	546	546
R10	Northern Africa	238	245	245	315	242	193	245	245	315	154	119	196	245	245	343	217	315	147	315	238	147
R11	Northern America	256	231	189	459	291	459	343	343	459	280	459	119	343	347	364	270	459	238	459	99999	238
R12	Polynesia	417	662	658	99999	99999	99999	99999	99999	99999	99999	658	529	119	658	99999	99999	99999	99999	99999	658	99999
R13	South America	228	203	203	382	263	382	228	228	382	217	333	319	228	119	424	263	382	217	382	333	217
R14	South-central Asia	179	221	158	221	207	179	221	221	221	179	221	193	221	221	119	158	221	154	221	151	154
R15	South-eastern Asia	130	203	168	315	168	315	172	172	315	172	315	207	172	252	231	119	315	172	315	252	172
R16	Southern Africa	280	284	301	99999	99999	99999	99999	459	99999	354	99999	350	99999	354	99999	403	119	99999	99999	99999	301
R17	Southern Europe	420	445	420	532	462	277	532	532	532	221	434	399	532	441	550	473	532	119	532	434	308
R18	Western Africa	462	466	389	595	462	595	595	595	595	462	99999	389	595	462	644	462	595	389	119	462	389
R19	Western Asia	280	280	270	280	298	280	280	99999	280	249	280	294	99999	280	277	298	280	231	280	119	231
R20	Western Europe	501	539	501	560	494	487	333	560	560	413	529	455	560	539	592	501	560	203	560	529	119

DCPD (euros) - Values are for two foldable jerrycans (0,14kg, 0,00042m^3)

	P8	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
R0	Australia and New Zeland	7	20	16	20	17	20	15	15	20	17	20	18	15	17	19	17	20	15	20	20	15
R1	Caribbean	11	7	9	11	14	11	11	11	11	11	11	9	11	9	17	11	11	11	11	11	9
R2	Central America	9	8	7	13	11	13	13	13	13	8	13	8	13	8	19	11	13	8	13	13	8
R3	Eastern Africa	25	25	21	7	28	32	32	32	32	25	32	24	32	25	38	28	32	21	32	25	21
R4	Eastern Asia	8	10	7	11	7	11	8	8	11	10	11	9	8	10	13	8	11	10	11	11	10
R5	Eastern Europe	32	28	28	32	31	7	32	32	32	28	99999	31	32	32	35	31	32	23	32	29	23
R6	Melanesia	7	14	8	14	8	14	7	8	14	12	14	8	11	12	12	8	14	11	14	14	11
R7	Micronesia	7	14	8	14	11	14	8	7	14	13	14	10	99999	12	99999	10	14	11	14	99999	11
R8	Middle Africa	27	26	99999	35	27	34	35	35	7	27	99999	23	35	26	38	27	35	23	35	27	23
R9	North Europe	31	35	31	39	34	33	39	39	41	7	31	34	39	35	39	35	39	25	39	31	31
R10	Northern Africa	14	14	14	18	14	11	14	14	18	9	7	11	14	14	20	12	18	8	18	14	8
R11	Northern America	15	13	11	26	17	26	20	20	26	16	26	7	20	20	21	15	26	14	26	99999	14
R12	Polynesia	24	38	38	99999	99999	99999	99999	99999	99999	99999	38	30	7	38	99999	99999	99999	99999	99999	38	99999
R13	South America	13	12	12	22	15	22	13	13	22	12	19	18	13	7	24	15	22	12	22	19	12
R14	South-central Asia	10	13	9	13	12	10	13	13	13	10	13	11	13	13	7	9	13	9	13	9	9
R15	South-eastern Asia	7	12	10	18	10	18	10	10	18	10	18	12	10	14	13	7	18	10	18	14	10
R16	Southern Africa	16	16	17	99999	99999	99999	99999	26	99999	20	99999	20	99999	20	99999	23	7	99999	99999	99999	17
R17	Southern Europe	24	25	24	30	26	16	30	30	30	13	25	23	30	25	31	27	30	7	30	25	18
R18	Western Africa	26	27	22	34	26	34	34	34	34	26	99999	22	34	26	37	26	34	22	7	26	22
R19	Western Asia	16	16	15	16	17	16	16	99999	16	14	16	17	99999	16	16	17	16	13	16	7	13
R20	Western Europe	29	31	29	32	28	28	19	32	32	24	30	26	32	31	34	29	32	12	32	30	7

Purchase Costs (euros)	
P1	4
P2	150
P3	10935
P4	2855
P5	5
P6	4
P7	19
P8	3

Variable costs (euros) Built with average salary		Fixed costs (euros) Built with GDP	
Australia and New Zeland	0,141	Australia and New Zeland	3390000
Caribbean	0,061	Caribbean	146710
Central America	0,034	Central America	815000
Eastern Africa	0,015	Eastern Africa	352800
Eastern Asia	0,107	Eastern Asia	2567100
Eastern Europe	0,063	Eastern Europe	1506000
Melanesia	0,023	Melanesia	552000
Micronesia	0,026	Micronesia	630000
Middle Africa	0,03	Middle Africa	712200
North Europe	0,15	North Europe	3603000
Northern Africa	0,029	Northern Africa	695000
Northern America	0,178	Northern America	4265000
Polynesia	0,026	Polynesia	630000
South America	0,038	South America	905500
South-central Asia	0,016	South-central Asia	395600
South-eastern Asia	0,061	South-eastern Asia	1474000
Southern Africa	0,029	Southern Africa	700000
Southern Europe	0,075	Southern Europe	1806400
Western Africa	0,006	Western Africa	143800
Western Asia	0,098	Western Asia	2357600
Western Europe	0,186	Western Europe	4461400



Warehouse location on a local level - Data set

The values of each of those sub-criteria, together with the values of the aggregated criteria are provided in the following pages.

Corruption

- C1: Perceived corruption index
- C2: Human development index
- C3: Employment rate
- C4: Political stability
- C5: GDP per capita rank minus HDI rank

Security

- C6: Victims of conflicts "one sided" over 20years, per number of inhabitants
- C7: Global peace index
- C8: Total affected per natural disasters per inhabitants

Accessibility

- C9: Number of airports
- C10: Merchant lines
- C11: Annual cargo load

Telecommunications

- C12: Telephones - main lines per inhabitants
- C13: Telephones - mobile cellular per inhabitants
- C14: Internet hosts per inhabitants

	Corruption						Security				Accessibility				Telecom			
	C1	C2	C3	C4	C5		C6	C7	C8		C9	C10	C11		C12	C13	C14	
Weighting factors	0,16	0,2	0,3	0,17	0,16		0	0,3	0,38		0,3	0,31	0,39	0	0,28	0,36	0,36	
Afghanistan	16	0	60	27	0	25	0	7	0	0	5	0	0	2	1	10	0	4
Albania	37	83	88	40	91	71	100	67	0	45	5	19	0	7	9	39	1	17
Algeria	34	77	87	40	58	64	8	51	96	48	21	26	0	14	9	50	0	21
American Samoa	0	0	70	0	0	21	100	0	0	22	5	0	0	2	15	2	11	9
Andorra	0	0	0	0	0	0	100	0	100	66	0	0	0	0	43	50	100	66
Angola	20	50	0	53	36	28	0	61	66	34	16	5	0	7	1	16	0	6
Anguilla	0	0	92	0	0	28	100	0	100	66	0	0	0	0	42	8	5	16
Antigua and Barbuda	0	86	89	0	61	54	100	0	0	22	5	100	0	29	43	79	10	44
Argentina	31	89	92	58	81	74	100	65	89	83	43	36	0	24	23	61	36	41
Armenia	31	80	93	27	84	67	100	51	36	56	5	0	0	2	20	24	3	15
Aruba	0	0	93	100	0	45	100	87	100	96	0	0	0	0	37	63	66	57
Australia	94	100	96	100	83	95	100	95	98	98	100	40	0	43	45	62	100	71
Austria	87	98	96	27	72	79	100	47	95	80	32	3	0	11	40	72	100	73
Azerbaijan	20	78	99	0	69	60	100	0	97	65	5	70	0	21	15	32	0	16
Bahamas	58	88	92	0	66	66	100	0	58	47	37	100	0	39	42	74	0	38
Bahrain	0	93	85	47	61	62	100	65	100	88	0	7	0	2	26	95	1	42
Bangladesh	23	54	98	53	76	65	93	61	0	41	16	32	0	14	1	14	0	5
Barbados	75	92	89	0	78	70	100	0	100	66	5	67	0	20	46	51	0	31
Belarus	22	84	98	53	75	71	100	54	100	84	5	0	0	2	37	44	3	27
Belgium	78	98	94	100	73	90	100	90	100	97	16	62	18	29	43	60	100	70
Belize	31	80	92	0	73	60	100	0	0	22	5	100	0	29	11	24	3	13
Benin	33	47	0	0	65	25	100	0	86	60	5	0	0	2	1	14	0	5
Bermuda	0	0	98	0	0	29	100	0	100	66	5	100	0	29	84	55	9	46
Bhutan	56	63	98	67	57	72	100	78	100	92	0	0	0	0	4	13	5	8
Bolivia	32	75	93	47	73	68	100	62	0	44	16	18	0	10	7	21	3	11
Bosnia-Hercegovenia	34	83	71	53	81	66	0	69	51	31	11	0	0	3	22	32	5	20
Botswana	62	69	93	93	22	71	100	80	54	73	16	0	0	5	7	47	1	20
Brazil	38	83	92	93	76	79	99	61	84	80	100	100	0	60	19	37	18	26
British Virgin Island	0	0	96	0	0	29	100	0	100	66	0	0	0	0	47	20	7	23
Brunei	0	95	96	0	55	57	100	0	100	66	0	6	0	2	20	54	15	31
Bulgaria	39	86	94	86	78	79	100	73	99	90	37	59	0	28	31	83	27	48
Burkina Faso	38	38	23	53	62	40	100	70	93	87	11	0	0	3	1	6	0	3
Myanmar	14	60	91	27	92	61	55	37	64	46	5	19	0	7	1	0	0	0
Burundi	20	39	0	47	76	32	0	37	0	0	5	0	0	2	0	2	0	1
Cambodia	19	59	97	27	76	61	0	52	0	3	5	100	0	29	0	11	0	4
Cameroon	25	53	70	33	60	51	92	54	99	81	27	0	0	9	1	15	0	6
Canada	94	100	94	100	78	94	100	91	100	97	100	100	0	60	61	34	58	50
Cape Verde Is	55	73	79	20	76	63	100	29	55	56	5	6	0	3	16	21	0	12
Cayman Islands	0	0	96	0	0	29	100	0	96	64	5	86	0	25	77	43	37	50
Central African Rep	22	36	92	0	66	49	21	0	98	36	43	0	0	14	0	2	0	1
Chad	17	40	0	20	56	23	0	20	26	3	16	0	0	5	0	6	0	2
Chile	74	90	93	100	83	89	100	81	72	81	21	35	0	16	20	52	19	31
China P Rep	39	79	96	53	79	73	95	62	0	42	53	100	100	85	26	25	4	18
Colombia	41	81	88	67	80	74	0	28	35	10	53	13	0	21	17	46	13	26
Comoros	27	59	80	0	84	54	100	0	0	22	16	100	0	32	3	3	0	2
Zaire/Congo Dem Rep	18	37	0	20	73	26	0	22	93	33	11	1	0	4	0	6	0	2
Congo	20	64	0	33	64	32	0	55	95	45	11	1	0	4	0	21	0	8
Cook Islands	0	0	87	0	0	26	100	0	100	66	0	21	0	6	49	7	69	41
Costa Rica	55	88	94	100	85	86	100	82	48	71	5	1	0	2	33	22	1	18
Cote d'Ivoire	22	45	0	20	54	25	19	50	100	53	43	0	0	14	3	21	0	9
Croatia	47	89	85	67	76	75	34	77	100	67	43	63	0	31	39	68	93	69
Cuba	46	88	98	53	100	80	100	65	0	45	16	9	0	8	9	1	0	3
Cyprus	69	94	96	86	0	74	100	63	100	87	21	100	0	34	56	85	68	71
Czech Rep	56	93	94	93	72	84	100	92	87	92	5	1	0	2	27	78	16	42
Denmark	100	98	98	100	74	95	100	93	100	98	75	100	0	51	50	69	100	75
Djibouti	32	53	41	0	61	38	100	0	0	22	5	0	0	2	2	5	0	3
Dominica	65	82	77	0	73	62	100	0	32	36	0	42	0	11	28	35	0	21
Dominican Rep	32	79	85	53	74	68	100	59	81	78	21	1	0	7	9	35	4	17
Ecuador	22	83	91	27	80	65	100	55	54	65	11	29	0	11	13	44	1	20
Egypt	30	74	91	67	59	68	89	73	100	87	48	53	0	30	13	22	1	12
El Salvador	42	77	94	80	69	75	100	0	0	22	5	0	0	2	15	53	1	24
Equatorial Guinea	18	74	70	53	10	50	100	66	99	88	5	1	0	2	2	22	0	8
Eritrea	28	46	0	0	79	27	100	0	0	22	0	4	0	1	1	1	0	0
Estonia	71	90	94	86	0	73	100	75	100	91	5	23	0	8	37	92	100	80

	Corruption						Security				Accessibility				Telecom			
	C1	C2	C3	C4	C5		C6	C7	C8		C9	C10	C11		C12	C13	C14	
Weighting factors	0,16	0,2	0,3	0,17	0,16		0	0,3	0,38		0,3	0,31	0,39	0	0,28	0,36	0,36	
Ethiopia	28	40	0	40	72	31	67	43	0	25	5	7	0	4	1	1	0	1
Falkland Islands (Islas Malvinas)	0	0	0	0	0	0	100	0	100	66	0	0	0	0	74	0	11	24
Faroe Islands	0	0	99	0	0	30	100	0	100	66	0	9	0	2	46	63	66	59
Fiji	0	77	92	0	74	55	100	0	75	55	11	7	0	5	11	29	5	15
Finland	97	99	94	100	78	94	100	93	100	98	100	77	0	53	32	71	100	71
France	74	99	93	100	80	90	100	80	99	93	100	100	100	100	54	54	87	66
French Polynesia	0	0	88	0	0	26	100	0	100	66	0	12	0	3	18	38	19	25
Gabon	33	75	79	53	32	59	100	64	92	84	32	2	0	11	2	48	0	18
Gambia The	20	49	0	47	69	32	100	68	94	87	5	4	0	3	4	28	0	11
Gaza Strip	0	0	59	0	0	18	100	0	100	66	0	0	0	0	23	42	0	21
Georgia	42	79	86	13	85	65	27	20	1	3	5	100	0	29	12	34	2	16
Germany	85	97	92	100	73	90	100	91	97	96	100	100	59	83	63	72	100	79
Ghana	42	55	89	73	79	70	100	73	85	84	5	3	0	3	2	20	0	8
Gibraltar	0	0	97	0	0	29	100	0	100	66	0	100	0	27	84	21	26	40
Greece	51	98	92	80	77	82	100	68	99	89	100	100	0	60	56	68	57	61
Greenland	0	0	91	0	0	27	100	0	100	66	0	2	0	1	60	70	93	76
Grenada	0	80	88	0	69	54	100	0	0	22	5	0	100	42	30	31	0	20
Guam	0	0	89	0	0	27	100	0	62	49	11	0	0	3	36	34	0	22
Guatemala	33	72	97	58	62	69	0	52	56	27	5	0	0	2	10	48	4	21
Guernsey	0	0	99	0	0	30	100	0	100	66	0	0	0	0	66	41	1	33
Guinea	17	44	0	58	65	32	91	59	84	76	11	0	0	3	0	1	0	0
Guinea Bissau	20	40	0	0	0	11	100	0	27	34	5	0	0	2	0	12	0	4
Guyana	28	75	0	0	82	33	100	0	0	22	5	6	0	3	14	22	3	13
Haiti	15	54	0	27	79	31	26	51	22	22	5	0	0	2	1	17	0	7
Honduras	28	74	72	53	72	62	90	46	22	44	11	97	0	30	10	33	1	15
Hong Kong (China)	87	97	96	0	63	73	100	0	100	66	5	100	0	29	53	91	44	64
Hungary	55	91	92	86	75	82	100	86	97	94	5	0	0	2	32	68	71	59
Iceland	96	100	98	100	81	96	100	99	100	100	32	2	0	11	59	69	100	78
India	37	63	93	93	67	74	84	40	0	30	100	100	100	100	3	16	1	7
Indonesia	28	75	92	80	80	74	76	66	80	71	48	100	0	43	7	21	1	10
Iran Islam Rep	25	80	88	27	60	61	100	54	0	41	11	59	0	19	35	27	0	20
Iraq	14	0	82	20	0	30	0	0	98	28	11	11	0	6	5	30	0	12
Ireland	83	99	94	93	74	90	100	93	100	97	48	23	0	22	49	72	100	76
Isle of Man	0	0	99	0	0	29	100	0	100	66	0	100	0	27	65	0	2	19
Israel	65	96	94	73	78	83	0	17	100	34	27	9	0	11	41	76	75	66
Italy	52	98	93	100	78	86	100	77	99	92	100	100	0	60	45	82	100	78
Jamaica	33	80	90	80	74	74	100	57	3	43	11	16	0	8	12	54	0	23
Japan	78	99	96	100	83	92	100	97	92	96	100	100	100	100	39	51	100	65
Jersey	0	0	98	0	0	29	100	0	100	66	0	0	0	0	78	56	1	42
Jordan	55	79	87	40	82	71	100	66	85	82	11	17	0	8	9	47	1	20
Kazakhstan	24	83	93	40	71	67	100	58	97	84	11	4	0	5	20	50	1	24
Kenya	23	55	60	40	76	52	100	47	0	38	16	1	0	6	1	18	0	7
Kiribati	33	0	98	0	0	35	100	0	100	66	0	34	0	9	4	0	0	1
Korea Dem P Rep	0	0	0	33	0	6	100	25	54	54	5	100	100	69	5	0	0	1
Korea Rep	60	96	97	58	0	68	100	76	93	89	11	100	0	30	48	55	3	34
Kosovo	0	0	60	0	0	18	100	0	100	66	0	0	0	0	5	16	0	7
Kuwait	46	94	98	67	56	77	100	77	100	92	5	30	0	10	19	65	0	29
Kyrgyzstan	19	72	82	0	85	56	100	0	97	65	0	0	0	0	9	24	4	13
Lao P Dem Rep	22	63	98	58	73	67	71	79	0	39	5	1	0	2	1	13	0	5
Latvia	54	89	95	86	74	82	100	71	100	90	5	17	0	6	28	60	37	43
Lebanon	32	82	91	40	66	67	100	35	97	77	11	26	0	10	17	19	3	13
Lesotho	34	51	55	0	67	43	100	0	0	22	5	0	0	2	2	13	0	5
Liberia	26	38	15	53	72	37	0	57	93	45	5	100	0	29	0	10	0	4
Lybia	0	87	70	58	73	60	100	71	100	90	0	13	0	3	13	44	0	20
Liechtenstein	0	0	99	0	0	29	100	0	100	66	0	0	0	0	56	49	84	63
Lithuania	49	90	95	86	74	82	100	76	100	92	5	36	0	11	22	84	86	67
Luxembourg	89	99	95	100	66	91	100	93	100	98	5	36	80	44	49	76	100	77
Macau	58	0	97	0	0	39	100	0	100	66	5	0	0	2	31	95	0	44
Macedonia FRY	39	83	66	47	79	64	100	61	0	43	11	0	0	3	22	45	7	25
Madagascar	37	55	0	6	87	32	100	63	0	44	11	6	0	5	1	7	0	3
Malawi	30	47	0	53	76	36	100	72	0	47	11	0	0	3	1	5	0	2
Malaysia	55	85	96	73	68	79	100	84	90	90	69	100	100	90	17	56	6	27
Maldives	30	77	0	0	71	32	100	0	77	56	5	23	0	8	8	50	2	21

	Corruption						Security				Accessibility				Telecom			
	C1	C2	C3	C4	C5		C6	C7	C8		C9	C10	C11		C12	C13	C14	
Weighting factors	0,16	0,2	0,3	0,17	0,16		0	0,3	0,38		0,3	0,31	0,39	0	0,28	0,36	0,36	
Mali	33	40	70	33	66	51	15	53	43	28	5	0	0	2	1	12	0	5
Malta	0	92	94	0	72	58	100	0	100	66	0	100	0	27	47	56	25	42
Marshall Is	0	0	64	0	0	19	100	0	92	62	0	100	0	27	7	1	0	2
Martinique	0	0	0	0	0	0	0	0	100	0	5	0	0	2	0	0	0	0
Mauritania	30	58	70	40	70	56	100	46	0	38	16	0	0	5	1	24	0	9
Mauritius	59	83	92	0	64	65	100	0	99	65	11	2	0	4	27	45	3	25
Mayotte	0	0	75	0	0	22	100	0	100	66	0	0	0	0	4	14	0	6
Mexico	39	87	96	67	77	77	99	54	64	68	100	43	0	44	17	38	37	32
Micronesia Fed States	0	0	78	0	0	23	100	0	36	38	0	2	0	1	8	15	3	9
Moldova Rep	31	74	98	47	82	71	100	66	0	45	0	31	0	8	24	26	20	23
Monaco	0	0	0	0	0	0	100	0	100	66	0	55	0	15	100	32	100	75
Mongolia	32	74	97	40	79	69	100	59	0	42	5	61	0	18	5	16	0	7
Montenegro	37	85	85	73	79	74	100	61	99	86	0	5	0	1	0	0	0	0
Montserrat	0	0	94	0	0	28	100	0	75	55	0	0	0	0	0	0	30	11
Morocco	38	67	98	47	62	67	97	70	94	86	53	28	0	25	7	35	3	16
Mozambique	28	38	79	58	66	57	0	73	0	10	11	2	0	4	0	9	0	4
Namibia	14	65	95	73	52	65	100	70	0	46	59	1	0	19	6	23	1	11
Nauru	0	0	10	0	0	3	100	0	100	66	0	0	0	0	13	7	1	7
Nepal	29	55	58	47	84	55	0	61	50	28	5	0	0	2	3	2	1	2
Netherlands	96	99	96	100	76	94	100	81	100	94	32	100	100	78	43	63	100	71
Netherlands Antilles	0	0	83	0	0	25	100	0	100	66	0	100	0	27	35	54	80	58
New Caledonia	0	0	83	0	0	25	100	0	99	65	27	2	0	9	26	48	26	34
New Zealand	100	98	96	100	79	95	100	100	99	100	85	10	0	31	39	62	100	69
Nicaragua	27	72	96	40	76	67	100	67	46	65	5	0	0	2	4	22	4	11
Niger	30	38	0	0	0	13	66	0	0	10	27	0	0	9	0	4	0	2
Nigeria	29	52	0	53	61	34	93	29	98	72	16	54	0	20	1	17	0	6
Niue	0	0	88	0	0	26	100	0	12	27	0	0	0	0	73	17	100	62
Northern Mariana Is	0	0	92	0	0	28	100	0	100	66	5	0	0	2	23	14	0	12
Norway	85	100	97	100	72	92	100	94	100	98	100	100	0	60	41	68	100	72
Oman	59	87	85	53	61	72	100	83	96	93	11	2	0	4	8	46	1	19
Pakistan	27	58	93	20	65	58	98	16	47	47	50	12	0	20	3	31	0	12
Palau	0	0	96	0	0	29	100	0	100	66	0	0	0	0	31	3	0	10
Panama	37	86	94	67	78	76	100	69	83	82	5	100	0	29	14	44	1	20
Papua New Guinea	22	53	98	47	63	62	85	58	68	66	11	17	0	8	1	3	0	1
Paraguay	26	78	95	53	80	70	100	63	62	71	5	18	0	7	6	39	1	16
Peru	39	81	92	66	76	74	36	60	5	21	11	6	0	5	9	32	4	15
Philippines	25	77	93	53	86	70	83	38	0	29	11	100	0	30	4	33	1	13
Poland	49	90	90	93	79	82	100	81	100	93	27	12	0	12	26	65	77	59
Portugal	66	93	92	93	76	86	100	92	91	93	48	93	0	41	37	76	66	62
Puerto Rico	62	0	88	0	0	37	100	0	98	65	11	2	0	4	25	52	0	26
Qatar	0	93	99	77	49	70	100	91	100	97	0	17	0	5	28	93	0	42
Romania	41	85	96	73	73	77	79	75	94	81	27	13	0	12	19	63	37	41
Russia	23	83	94	47	59	66	49	18	91	49	85	100	0	55	30	74	13	40
Rwanda	32	45	0	47	72	34	0	63	0	7	5	0	0	2	0	4	0	1
St Helena	0	0	86	0	0	26	100	0	75	55	0	0	0	0	28	0	15	13
Saint Kitts and Nevis	0	86	96	0	66	57	100	0	100	66	0	100	0	27	61	15	0	22
St Lucia	76	85	80	0	76	66	100	0	100	66	11	0	0	3	31	40	0	23
Saint Pierre and Miquelon	0	0	90	0	0	27	100	0	100	66	0	0	0	0	66	0	0	18
St Vincent and The Grenadines	70	79	85	0	67	64	100	0	92	62	5	100	0	29	19	53	0	25
Samoa	47	79	0	0	86	38	100	0	100	66	5	1	0	2	9	24	20	18
San Marino	0	0	97	0	0	29	100	0	100	66	0	5	0	1	68	35	84	62
Sao Tome and Principe	0	66	0	0	85	27	100	0	100	66	0	0	0	0	4	9	2	5
Saudi Arabia	38	86	91	47	57	68	93	54	100	81	48	46	0	28	14	61	2	27
Senegal	37	52	52	47	0	40	61	62	72	61	5	0	0	2	2	20	0	8
Serbia	37	85	81	47	78	68	100	60	99	86	0	0	0	0	28	51	0	26
Seychelles	52	86	98	0	68	66	100	0	0	22	5	6	0	3	27	57	1	29
Sierra Leone	20	34	0	47	67	29	0	72	98	52	5	100	0	29	0	8	0	3
Singapore	99	95	98	100	56	91	100	80	100	93	5	100	100	69	39	74	69	62
Slovakia	54	90	92	100	74	84	100	84	99	94	5	40	0	12	20	68	50	48
Slovenia	72	95	93	100	76	89	100	92	100	97	11	23	0	10	41	58	14	38
Solomon Is	31	61	0	0	80	30	100	0	97	65	0	0	0	0	1	1	2	2

	Corruption						Security				Accessibility				Telecom			
	C1	C2	C3	C4	C5		C6	C7	C8		C9	C10	C11		C12	C13	C14	
Weighting factors	0,16	0,2	0,3	0,17	0,16		0	0,3	0,38		0,3	0,31	0,39	0	0,28	0,36	0,36	
Somalia	11	0	0	0	0	2	0	1	0	0	5	1	0	2	1	4	0	2
South Africa	53	69	78	73	36	65	77	46	0	30	100	2	0	33	9	53	10	25
Spain	70	98	86	93	79	86	88	82	100	89	100	100	0	60	44	73	30	50
Sri Lanka	34	77	95	73	79	75	0	35	0	0	5	21	0	7	13	23	0	12
Sudan	17	54	81	27	66	53	0	13	47	10	5	2	0	2	1	11	0	4
Suriname	39	80	91	0	66	60	100	0	58	47	5	1	0	2	17	41	0	19
Swaziland	39	56	60	47	44	51	100	65	0	45	11	0	0	3	4	20	1	9
Sweden	100	99	94	100	79	95	100	93	100	98	100	100	0	60	59	70	100	78
Switzerland	97	99	97	100	72	94	100	89	99	96	37	28	0	20	64	65	100	77
Syrian Arab Rep	23	76	91	33	74	64	100	51	57	65	11	61	0	20	17	21	0	12
Taiwan	61	0	96	93	0	55	100	79	100	93	0	81	0	22	60	65	86	71
Tajikistan	22	71	98	0	86	61	100	0	0	22	5	0	0	2	4	2	0	2
Tanzania Uni Rep	32	52	0	66	75	39	98	71	18	53	11	7	0	5	0	14	0	5
Thailand	38	81	99	40	71	71	60	46	0	23	37	100	100	80	10	48	6	23
Timor-Leste	24	50	80	0	81	51	100	0	99	66	0	1	0	0	0	4	0	1
Togo	29	49	0	0	77	27	100	0	81	57	5	8	0	4	1	12	0	5
Tokelau	0	0	0	0	0	0	100	0	100	66	0	0	0	0	20	0	72	31
Tonga	26	80	87	0	94	62	100	0	12	27	5	10	0	4	17	24	61	35
Trinidad and Tobago	39	86	95	73	0	65	100	59	99	86	11	7	0	5	25	50	48	42
Tunisia	47	79	86	58	66	70	100	78	98	92	21	6	0	9	12	46	0	20
Turkey	49	82	92	53	61	71	54	44	95	61	32	100	0	37	25	52	14	31
Turkmenistan	19	75	40	20	66	44	100	50	100	83	0	6	0	2	9	10	0	6
Turks and Caicos Islands	0	0	90	0	0	27	100	0	100	66	0	1	0	0	25	5	40	23
Tuvalu	0	0	0	0	0	0	100	0	100	66	0	63	0	17	7	6	100	40
Uganda	28	51	0	47	76	35	0	56	35	19	5	0	0	2	0	8	0	3
Ukraine	27	81	97	33	79	68	100	58	91	82	21	100	0	34	27	73	4	36
United Arab Emirates	0	93	98	47	53	65	100	61	100	87	0	46	100	53	29	100	31	56
United Kingdom	83	97	95	93	72	89	100	80	96	91	100	100	100	100	53	72	51	59
United States	74	98	93	100	66	88	77	75	57	64	100	100	100	100	52	51	100	69
Uruguay	78	89	92	86	85	87	100	83	77	84	5	13	0	5	27	53	52	45
Uzbekistan	19	72	99	27	81	65	100	52	86	78	16	0	0	5	6	23	1	10
Vanuatu	31	71	98	0	69	60	100	0	0	22	11	43	0	15	4	7	2	4
Venezuela	20	85	92	40	72	66	96	46	97	79	32	49	0	24	19	55	2	26
Viet Nam	29	74	95	53	82	71	100	77	0	49	11	100	0	30	12	23	0	12
Virgin Is (US)	0	0	94	0	0	28	100	0	100	66	21	1	0	7	63	44	16	39
Wallis and Futuna	0	0	85	0	0	25	100	0	100	66	0	6	0	2	12	0	0	3
Palestine (West Bank)	0	76	84	0	91	55	100	0	100	66	0	0	0	0	14	26	0	13
Yemen	25	59	65	27	66	51	100	38	99	78	11	3	0	4	4	8	0	4
Zambia	30	47	50	58	63	50	100	72	0	47	27	0	0	9	1	14	0	5
Zimbabwe	19	0	20	33	0	15	100	33	0	34	48	0	0	16	3	7	1	3

The list of sub-criteria has been chosen thanks to the principal component analysis (see section 14.3 on page 152). The list below provides all sub-criteria analysed. Given the size of the table (50 columns x 235 rows), we did not detail all values. Other combinations of those criteria, such as values divided by the surface or the number of inhabitants were also looked at.

- Total number of natural crisis over 10 years (EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.net – Université Catholique de Louvain – Brussels – Belgium)
- Total number of affected by natural crisis over 10 years (EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.net – Université Catholique de Louvain – Brussels – Belgium)
- Total number of natural crisis over 10 years per surface
- Total number of affected by natural crisis over 10 years per inhabitants
- GDP (current US dollar) (World bank group)
- Improved sanitation facilities urban (% of urban population with access) in 2006 (World bank group)
- Improved water source (% of population with access) in 2006 (World bank group)
- Roads paved (% of total roads) in 2000 (World bank group)
- Agricultural land (% of land area) in 2005 (World bank group)
- GDP growth (annual %) (World bank group)
- GNI per capita PPP (dollar) (World bank group)
- GNI PPP (dollar) (World bank group)
- Perceived corruption index (http://www.transparency.org/policy_research/surveys_indices/cpi/2008)
- Conflicts "one sided" over 20ans (ucdp)
- Civilian victims of conflicts over 5ans (ucdp)
- Conflicts "one sided" over 20ans per inhabitants
- Civilian victims of conflicts over 5ans per inhabitants
- Human Development Index Value (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- Life Expectancy at birth (years) (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- Adult Literacy Rate (%aged 15 and above) (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)

- Combined gross enrolment ratio in education (%) (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- GDP per Capita (PPP US dollar) (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- Life Expectancy index (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- Education index (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- GDP index (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- GDP per capita rank minus HDI rank (http://hdr.undp.org/en/media/HDI_2008_EN_Tables.pdf)
- GDP - per capita (PPP) USdollar (CIA)
- Unemployment rate (CIA)
- Ports and terminals (CIA)
- Number of airports per surface
- Ports and terminals per surface
- Number of airports per inhabitants
- Ports and terminals per inhabitants
- Number of airports (http://www.levoyageur.net/aeroports.php)
- Telephone main lines 2005 per 1000 inhab (Human Development Report 2007/2008 http://www.hdr.undp.org)
- Cellular phones subscribers 2005 per 1000 inhab (Human Development Report 2007/2008 http://www.hdr.undp.org)
- Internet users 2005 per 1000 inhab (Human Development Report 2007/2008 http://www.hdr.undp.org)
- Telephones-mainlinesinuse (CIA)
- Telephones - mobile cellular (CIA)
- Internet hosts (CIA)
- Internet users (CIA)
- Telephones - MAIN LINES per 1000inhab (CIA)
- Telephones - mobile cellular per 1000inhab (CIA)
- Internet hosts per 1000inhab. (CIA)
- Internet users per 1000inhab. (CIA)

- Latitude (http://www.mobilgistix.com/Resources/GIS/Locations/average-latitude-longitude-countries.aspx)
- Longitude (http://www.mobilgistix.com/Resources/GIS/Locations/average-latitude-longitude-countries.aspx)
- Superficie
- Population total (World bank group)
- Population (CIA)
- Urban growth rate 2005-2010 (http://web.unfpa.org/swp/2007/english/notes/indicators/e_indicator2.pdf)
- % Urban population (http://web.unfpa.org/swp/2007/english/notes/indicators/e_indicator2.pdf)
- Annual cargo traffic 2008 (Airports Council International)
- Merchant lines (CIA)
- Navigable waterways (CIA)

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